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COMPUTER FAMILY ARCHITECTURE SELECTION COMMITTEE FINAL REPORT. --ETC(U)
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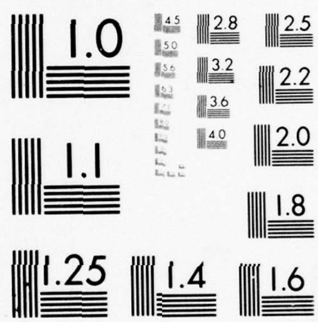


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Research and Development Technical Report

ECOM-4535

# COMPUTER FAMILY ARCHITECTURE SELECTION COMMITTEE - FINAL REPORT, VOLUME VI - LIFE CYCLE COST MODELS

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September 1977

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This report consists of a summary and nine (9) volumes. It is the result of joint Army/Navy work. The complete report may be separately published by the Naval Research Laboratories.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Family Architecture, BOTTOM-UP MODEL, TOP DOWN MODEL, Life Cycle Cost.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the mathematical information, input data, and results of a methodology and two life-cycle requirements models for comparing computer architectures with respect to life-cycle costs: the Top Down (TD) model and the Bottom-Up (BU) model. The methodology and models were formulated to help the Army and Navy select a single computer architecture for a software-compatible family of military computers for the 1980's. Three candidate architectures were compared: The IBM System/370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32. The data derived using the BU model indicates that the PDP-11



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20. architecture would be the most cost-effective architecture for the military embedded computer environment in most circumstances. The data derived using the TD model indicates that for software-to-hardware cost ratios greater than about one the IBM 370 architecture is superior, for ratios less than about one fourth the Interdata 8/32 architecture is best, and for ratios in between the PDP-11 architecture is most desirable. The differences in the results of the models are explained in terms of uncertainties in the input data, and the debatable validity of some of the model's assumptions.

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# 1. INTRODUCTION/BACKGROUND

## a. INTRODUCTION

The final report of the Army/Navy Computer Family Architecture (CFA) Selection Committee consists of nine volumes, which together describe the background, activities, and technical findings leading to the recommendation by that Committee for a computer architecture to be used in a family of software-compatible military computers. This is the sixth volume of that report. It describes the methodology used to compute life-cycle costs of military computer implementations based on CFA candidates and it presents the results of applying this methodology to two different life-cycle models.

Volume I explains the background, rationale and organization of the Computer Family Architecture (CFA) effort.

Volume II describes the technical issues addressed by the Selection Committee for preliminary evaluation of the architecture candidates and describes the results of that technical evaluation.

Volume III describes test program specification and development and the application of these test programs to evaluation of architectural efficiency of CFA candidates.

Volume IV presents hardware language (ISP) descriptions of the candidate architectures and describes the ISP interpreter facility used to simulate and gather data from the test program runs.

Volume V addresses the determination of support software requirements and the evaluation of the available support software of the candidate architectures with respect to these requirements.

Volume VII addresses the financial, technical, and legal issues arising out of discussions with the owner/manufacturers of the candidate computer architectures and describes the outcome of these discussions.

Volume VIII describes the considerations of the Selection Committee during the final selection process and the synthesis of the architecture evaluation on data that formed the basis for the final selection.

Volume IX addresses controversial issues and questions that arose during the course of the CFA effort.

The two life-cycle models described in this volume are called the Bottom-Up (BU) and Top-Down (TD) models. These models were originally described in two separate internal reports (SvirW76a), (CornJ76a). This volume merges and elaborates on those reports.

Section 2 describes the mathematical formulation, input data, and results of the BU model. This model was developed and its results computed by William R. Svirsky, Al Irwin, and Tom Giles of System Development Corporation, West Long Branch, New Jersey, under the sponsorship and direction of Aaron H. Coleman of the U. S. Army Electronics Command, Ft. Monmouth, New Jersey. William Svirsky wrote most of the description contained herein.

Section 3 describes the mathematical formulation, input data, results and error analysis of the TD model. John J. Cornyn and William R. Smith of the Naval Research Laboratory formulated the model. J. Cornyn carried out the computations on the NRL PDP-10 timesharing system and wrote most of the text.

Three candidate architectures were compared using the models: the IBM 370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32. The BU model predicted that the PDP-11 architecture would be the most cost-effective architecture for the military embedded computer environment in almost all circumstances. The TD model predicted that for software-to-hardware ratios greater than about one, the IBM 370 architecture is superior, for ratios less than about one-fourth the Interdata 8/32 architecture is best, and for ratios in between the PDP-11 architecture is desirable. Section 4 discusses the results of the models and explains the differences on the basis of uncertainties in the input data and the debatable validity of some of the models' assumptions.

R. P. Estell, of the Fleet Combat Direction Systems Support Activity, San Diego, California, and Capt Robert P. Sabin, Project Manager of the SAM-D Missile System, Redstone Arsenal, Alabama, contributed to the formulation of the life-cycle cost methodology.

b. BACKGROUND

At the third meeting of the CFA Selection Committee, on 18-20 February 1976, at the Naval Postgraduate School, Monterey, California, Dr. Bruce Wald (NRL) addressed the Selection Committee. He urged that final selection of the CFA be based on considerations meaningful and convincing to DoD management, in particular the cost benefits/penalties of the various choices. Consequently, a Final Selection Methodology Subcommittee was established (R. Estell (FCDSSA), R. Sabin (SAM-D), and W. Smith (NRL), chairman) to develop a methodology for including cost considerations in the final CFA selection.

At the fourth Committee meeting on 28-29 February at NRL, Washington, D.C., W. Smith presented the methodology developed by the Final Selection Methodology Subcommittee [EsteR76]. This methodology provided the approach to convert computer resource requirements (processor performance, storage, software) into dollar costs and to derive those costs for the life-cycle requirements of relevant military computer uses. In particular, he proposed that this methodology be applied to a model (later designated as the top-down (TD) model) of military computer requirements, based on extrapolating trends in DoD computer resource requirements and expenditures. The Committee accepted this approach.

Subsequently, at a meeting at USAECOM, Ft. Monmouth, N.J., A. Coleman (ECOM) proposed to W. Smith that an additional computer resource requirements model (later designated as the bottom-up (BU) model), complementary to the TD model, be used to compute military computer life-cycle costs. The BU model was based on specific, individual computer systems in existing or planned Army applications. The System Development Corporation (SDC), under contract to ECOM,

was available to perform the BU data gathering and computations. Since it was believed that the use of both the TD and BU models would help to check the consistency and validity of the results, it was agreed that both results would be presented to the Selection Committee at its fifth and final meeting in August 1976.

In order to assist the reduction of software requirements to costs, it was further agreed that SDC would attempt to gather data from software development projects in SDC and to formulate a support-software-availability/software-development-cost relationship from that data. The results were subsequently used in the reduction of both models to life-cycle costs.

## References


CornJ76a Cornyn, J. J., "A Life Cycle Cost Model for Comparing Computer Architectures," Naval Research Laboratory, Washington, D.C., October 6, 1976 (unpublished manuscript).

EsteR76 Estell, R. G., Sabin, R. P., and Smith, W. R., "Final CFA Selection Methodology Subcommittee Preliminary Report," April, 1976.

SvirW76a Svirsky, W. "Life Cycle Cost Analysis of Computer Family Architecture (CFA) Finalists with Army Embedded Computer Systems," System Development Corporation, West Long Branch, New Jersey, SDS CENTACS Customer Produce #43, September, 1976 (unpublished manuscript).

CONTENTS - BU Model

## 2. THE BOTTOM-UP MODEL

### a. INTRODUCTION

Section 2 provides the results of a life-cycle cost analysis of three competing architectures - IBM 370, DEC PDP-11, and Interdata 8/32- as applied to fifteen current Army embedded-computer systems.

As indicated in the Table of Contents, Section 2 discusses the background events leading to the initiation of this analysis, describes the basic approach or methodology used, tabulates the results obtained and presents the conclusions.

### b. BACKGROUND

At the 4th meeting of the CFA Selection Committee on 28/29 April 1976 at NRL, Washington, D. C., W. Smith (NRL) presented a methodology for quantitative/relative evaluation of the life-cycle costs of the DOD computer resource requirements as a function of the three CFA finalists under consideration (EsteR76). In addition, a model (later designated as the top-down (TD) model) of military computer resource requirements, based on projections of trends in military computer resource expanditures and requirements, was proposed to be used in conjunction with the methodology for computing life-cycle costs. Subsequently, A. Coleman (ECOM CENTACS) proposed a complementary requirements model (later designated as the bottom-up (BU) model) for military computer resources based on specific, individual embedded-computer systems (ColeA76a). At a meeting on 17 May 1976 involving personnel from NRL, ECOM (CENTACS) and SDC, it was agreed that the life-cycle cost analyses to be presented to the CFA Selection Committee at its 5th meeting in August 1976 would include both the TD and BU models (ColeA76b). At this meeting, a model prepared by SDC for CENTACS (SvirW76b) was amended to serve as the basis for the BU model described in this report.

### c. BASIC APPROACH

#### (1) Overview

The computer resource life cycle cost was estimated for each of 15 Army embedded-computer systems (employing each of the three CFA finalists) and for all systems. Estimates were made for 1976 and for 1985 production procurements. The lowest cost CFA for each system and for all systems was selected for 1976 and 1985 procurements. The systems are designated #1 to #15 and are listed in Table 2-1. As shown in Table 2-1 these systems are in various phases of their life cycle.

#### (2) Total Life Cycle Cost

The computer resource life cycle cost for a given system and a specific CFA is defined as:

$$C_{ij} = Hw_{ij} + ASw_{ij} \tag{2.1}$$

where $C_{ij}$ = computer resource life cycle cost of system i using architecture j

TABLE 2-1

Army Embedded - Computer Systems

| SYSTEM # | SYSTEM MISSION | LIFE CYCLE PHASE |
|---|---|---|
| 1 | Medium Search | Engineering Development |
| 2 | Medium Command & Control | Initial Production |
| 3 | Small Search | Conceptual Phase |
| 4 | Large Command and Control | Limited Production |
| 5 | Medium Command and Control | Advanced Development |
| 6 | Large Command and Control | Advanced Development |
| 7 | Small Command and Control | Advanced Development |
| 8 | Large Communications | Engineering Development |
| 9 | Small Communications | Engineering Development |
| 10 | Small Communications | Advanced Development |
| 11 | Small Special Purpose | Engineering Development |
| 12 | Large Data Management | Deployment |
| 13 | Medium Search | Advanced Development |
| 14 | Medium Data Management | Conceptual Phase |
| 15 | Small Guidance and Control | Conceptual Phase |

$Hw_{ij}$ = hardware life cycle cost of system i using architecture j

$ASw_{ij}$ = applications software life cycle cost of system i using architecture j

(3) Hardware Life Cycle Cost (LCC)

(a) Total Hardware LCC

The computer hardware life cycle cost for a given system using a specific CFA is defined as:

$$Hw_{ij} = n_i \, L_h \, (P_{ij} + MM_{ij} + SM_{ij}) \qquad (2.2)$$

where

$n_i$ = number of units to be produced for system i

$L_h$ = hardware life cycle cost factor, i.e., ratio of total hardware life cycle cost to hardware acquisition cost. This factor is assumed to be 2 for a 10-year life cycle

$P_{ij}$ = processor acquisition cost for system i using architecture j

$MM_{ij}$ = main memory acquisition cost for system i using architecture j

$SM_{ij}$ = secondary memory acquisition cost for system i using architecture j

(b) Processor Acquisition Cost

The processor acquisition cost for system i using architecture j is defined as:

$$P_{ij} = K(a_{ij} \, Mr_i)^{0.4} \qquad (2.3)$$

where

K = constant relating to processor cost, derived as shown below

$a_{ij}$ = processor speed ratio for architecture j for system i derived from architecture test data as described in the Appendix, Section 2.7

$Mr_i$ = operating speed in MIPS* required for system i, derived from system proponents

*MIPS = millions of instructions per second

Equation (2.3) and Ko are derived in [SvirW76b] from equation (2.4) below;

$$Ma_{ij} = Ko\ (cost)^{2.5} \qquad (2.4)$$

or $$Ko = \frac{Ma_{ij}}{(cost)^{2.5}} \qquad (2.5)$$

where $$Ma_{ij} = a_j\ Mr_i \text{ stated in MIPS} \qquad (2.6)$$

thus Ko is the ratio $$\frac{MIPS}{(cost)^{2.5}} \qquad (2.7)$$

Examination of recent cost/speed data for several military processors shows that speeds of 0.5 MIPS and corresponding processor costs of $48,000 are representative values. Substituting these figures into equation (2.7) yields a value of:

$$Ko = 9.9 \times 10^{-13}$$

Equation (2.4) can be restated in terms of cost, $P_{ij}$, as:

$$P_{ij} = \left(\frac{Ma_{ij}}{Ko}\right)^{0.4} \qquad (2.8)$$

substituting $$K = \left(\frac{1}{Ko}\right)^{0.4} = \left(\frac{1}{9.9 \times 10^{-13}}\right)^{0.4} = 6.3 \times 10^{4} \qquad (2.9)$$

This value of K is used in subsequent calculations for 1976 processor cost estimates and is reduced by a factor of 10 for 1985 processor cost estimates based on an assessment of hardware cost reduction over the next decade.

(c) Main Memory Acquisition Cost

The main memory acquisition cost for system i using architecture j is defined as:

$$MM_{ij} = c_b\ (b_{ij}\ PM_i + DM_i) \qquad (2.10)$$

where:

$MM_{ij}$ = main memory acquisition cost (dollars) for system i using architecture j

$b_{ij}$ = static storage ratio for architecture j and system i, derived from the architecture test results as described in the Appendix, Section 2.7

$PM_i$ = main memory (in bits) required for program storage in system i; $M_i$ is derived from system proponents; P is estimated fraction of $M_i$ dedicated to program storage vs. data storage

$DM_i$ = main memory (in bits) required for data storage in system i; $M_i$ is derived from system proponents; D is estimated fraction of $M_i$ dedicated to data storage vs. program storage

$C_b$ = cost per bit of main memory derived from the study of Air Force ADP requirements through the 1980's [SADPR74] and Turn's data in his book, Computers in the 1980's [TurnR74]. Examination of the price per bit of recent militarized memory systems indicates an average cost of 4 cents per bit; i.e., $5000 per 16K byte memory module. This value is used in 1976 cost estimates; 0.4 cents is assumed in 1985 cost estimates.

(d) Secondary Memory Acquisition Cost

The secondary memory acquisition cost for system i using architecture j is defined as:

$$SM_{ij} = C_a (D_{ij}\ P'Ma_i + D'Ma_i) \tag{2.11}$$

where:

$SM_{ij}$ = secondary memory acquisition cost (dollars) for system i using architecture j

$D_{ij}$ = static storage ratio for architecture j for system i, derived from the architecture test results as described in the Appendix, Section 2.7

$P'Ma_i$ = secondary memory (in bits) required for program storage in system i; $Ma_i$ is derived from system proponents while P' is the estimated fraction of $Ma_i$ used for program storage vs. data storage

$D'Ma_i$ = secondary memory (in bits) required for data storage in system i; $Ma_i$ is derived from system proponents while D' is the estimated fraction of secondary memory used for data storage vs. program storage

$C_a$ = cost per bit of secondary memory derived from the study of Air Force ADP requirements through the 1980's [SADPR74] and Turn's data [TurnR74].

Examination of the price per bit of current militarized disc systems indicates an average cost of 0.2 cents per bit, e.g.; a 36M bit disc system at $72,000. This value is used in 1976 cost estimates; a cost reduction of 10:1 in the next 10 years is assumed so that a price of 0.02 cents per bit is used in 1985 cost estimates.

(4) Applications Software Life Cycle Cost

The applications software life cycle cost for system i using architecture j is defined as:

$$ASw_{ij} = Cs_j \; S_i \; L_s \qquad (2.12)$$

where $Cs_j$ = cost ($) per instruction of applications software for architecture j

$S_i$ = applications software size (in instructions) for system i, derived from system proponents

$L_s$ = applications software life cycle cost factor, i.e., ratio of applications software life cycle cost to initial acquisition cost

Ls, software life cycle cost factor, was taken basically from Fisher's report [FishD74, p.64] which places modifications and retrofits to software at four to five times the cost of the initial product. Thus by taking the midpoint and adding the initial cost as one, we have a value of Ls = 5.5.

$Cs_j$, cost per instruction of application software for architecture j, is based on the experience of System Development Corporation with five large scale (24K instructions to 500K instructions) software efforts. The data was compiled by sending questionnaires to the program managers. Program managers responded with: the cost of software production, the number of instructions produced, and for thirteen software tools they estimated what would be the percent increase in project cost if the tool were not available and how much less the project cost would be if the ideal tool were available. From generalizations of this data, it was possible to construct the curves shown in Figure 2-1.

These curves show the variation of cost per instruction as a function of the Tool Availability Index (TAI) for three conditions; (A) worst case, (B) best case and (C) derived median. It should be recognized that the results are largely judgmental and that examples can also be found which yield costs per instruction above and below the worst and best case curves of Figure 2-1. The Tool Availability Index (TAI) is defined as the ratio of available software tools to the ideal set of software tools. The "ideal set" is defined in a separate report by the Software Evaluation Methodology Subcommittee [WagnJ76].

By knowing the TAI for a given architecture for any point in time, one can enter Figure 2-1 and obtain an estimated cost per instruction. As the percentage of available software tools increases the cost per instruction of application software can be seen to diminish. The 1976 TAI for each CFA finalist was derived from the report of the Software Evaluation Committee [WagnJ76] as 34%, 50% and 73% for the Interdata 8/32, DEC PDP-11 and IBM S/370 architectures, respectively.* The average of these values is 52% and is indicated graphically in Figure 2-1. The cost per instruction for the average TAI is approximately $25, $10 and $17 for conditions A, B and C, respectively.

*A subsequent refinement of the data in the SEC report changes these percentages to 37%, 54% and 77%. The changes proved to have no significant impact on the data presented herein.

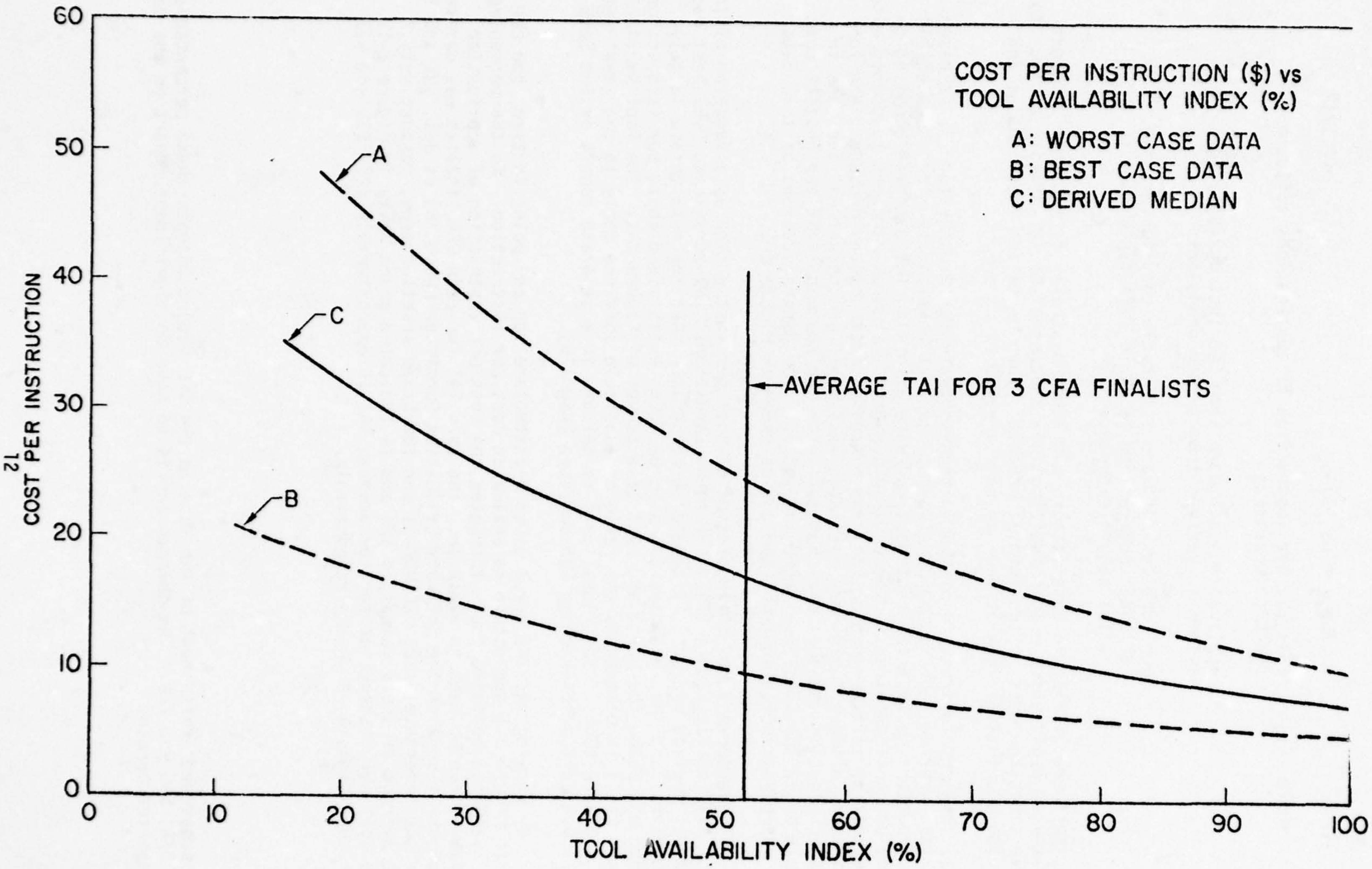
COST PER INSTRUCTION ($) vs
TOOL AVAILABILITY INDEX (%)
A: WORST CASE DATA
B: BEST CASE DATA
C: DERIVED MEDIAN
AVERAGE TAI FOR 3 CFA FINALISTS
A
B
C
COST PER INSTRUCTION
TOOL AVAILABILITY INDEX (%)
0
10
20
30
40
50
60
70
80
90
100

Figure 2-1

d. RESULTS

(1) System Proponent Data

To obtain values of $n_i$, $Mr_i$, $M_i$, $Ma_i$, and $S_i$, a letter was sent from ECOM to fifteen project managers requesting values for their particular system. The responses are tabulated in Table 2-2 . This table indicates that:

(a) The number of installations required ($n_i$) ranges from 8 to 3325 per system for a total of 6277 computers for all 15 systems.

(b) MIPS required ranges from .02 for System #12 (Large Data Management) to 1.33 for System #1 (Medium Search).

(c) Estimated main memory used for programs ($PM_i$) ranges from .006 to 13.6 Mbits. The average value of $PM_i$ is 2.3 Mbits or approximately 288K bytes per system.

(d) The number of applications software instructions ($S_i$) varies from 1000 to 375,000 per system. The average value of $S_i$ is 106,000 instructions.

(2) Processor Life Cycle Cost

The parametric data required for processor life cycle cost computations is shown in Table 2-3a. The processor speed ratio ($a_{ij}$) is computed in the Appendix, Section 2.7, from the architecture test results. The total processor life cycle cost for each system was computed as described in paragraph 2.3.3.2 and is shown in Table 2-3b for 1976 and 1985 procurements. The <u>unit</u> processor life cycle cost for each system is shown in Table 2-3c. The average unit processor life cycle cost for all systems and architectures is $86,400 in 1976.

The average unit processor life cycle costs of the DEC PDP-11 and Interdata 8/32 architectures are 8.2% and 6.4% below the average; the cost for IBM S/370 architecture is 14.5% above the average.

(3) Main Memory Life Cycle Cost

The parametric data required for main memory life cycle cost computation is shown in Table 2-4a. The static storage ratio ($b_j$) is computed in the Appendix, Section 2.7, from the architecture test results. The total main memory life cycle cost for each system was computed as described in paragraph 2.3.3.3 and is shown in Table 2-4b for 1976 and 1985 procurements. The <u>unit</u> main memory life cycle cost for each system is shown in Table 2-4c. The average unit main memory life cycle cost in 1976 for all systems and all architectures is $232,500. The costs using the PDP-11 and 8/32 architectures are 13.9% and 12.7% below the average while the cost using the IBM S/370 is 26.6% above the average.

Table 2-2

System Proponent Data

| Sys. # | System Mission | $n_i$ | $Mr_i$ (MIPS) | $*PM_i$ | $*DM_i$ | $*PMa_i$ | $*DMa_i$ | $S_i$** |
|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 1.33 | .414 | .101 | 1.9 | 7.7 | 32 |
| 2 | Medium Command and Control | 27 | .26 | 1.638 | .412 | 2.2 | 8.8 | 144 |
| 3 | Small Search | 100 | 1.00 | .512 | .128 | 2.8 | 11.2 | 20 |
| 4 | Large Command and Control | 178 | .20 | 13.600 | 3.400 | 4.0 | 16.0 | 375 |
| 5 | Medium Command and Control | 64 | .50 | 1.600 | .400 | 15.8 | 63.2 | 47 |
| 6 | Large Command and Control | 30 | .40 | 3.321 | .820 | 8.4 | 33.6 | 250 |
| 7 | Small Command and Control | 832 | .75 | .618 | .152 | .4 | 1.6 | 100 |
| 8 | Large Communications | 616 | .18 | 3.200 | .800 | 13.4 | 52.0 | 175 |
| 9 | Small Communications | 800 | .16 | .116 | .031 | 0 | 0 | 8 |
| 10 | Small Communications | 9 | .53 | .408 | .102 | 3.2 | 12.8 | 83 |
| 11 | Small Special Purpose | 30 | .48 | .328 | .082 | .1 | .3 | 14 |
| 12 | Large Data Management | 16 | .02 | 1.600 | .400 | 573.4 | 2293.6 | 324 |
| 13 | Medium Search | 50 | .35 | 3.712 | .928 | 3.2 | 12.8 | 28 |
| 14 | Medium Data Management | 8 | .80 | 3.200 | .800 | 1912.0 | 7648.0 | 1 |
| 15 | Small Guidance and Control | 3325 | .20 | .006 | .002 | 0 | 0 | 1 |

* P and D are fractions applied to the proponent's stated memory requirements which reflect an estimate of memory used for programs (P) vs. data (D). Values are expressed in megabits.

** $S_i$ stated in $10^3$ instructions.

Table 2-3a

Processor Life Cycle Cost Parameters

| System # | System Mission | # Units $n_i$ | $Mr_i$ (MIPS) | Processor Speed Ratio, $a_j$ INTERDATA | DEC PDP11 | IBM S370 |
|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 1.33 | 0.81 | 0.92 | 1.28 |
| 2 | Medium Command and Control | 27 | .26 | 0.81 | 0.81 | 1.39 |
| 3 | Small Search | 100 | 1.00 | 0.84 | 0.78 | 1.28 |
| 4 | Large Command and Control | 178 | .20 | 0.79 | 0.78 | 1.44 |
| 5 | Medium Command and Control | 64 | .50 | 0.81 | 0.78 | 1.41 |
| 6 | Large Command and Control | 30 | .40 | 0.79 | 0.83 | 1.38 |
| 7 | Small Command and Control | 832 | .75 | 0.77 | 0.77 | 1.47 |
| 8 | Large Communications | 615 | .18 | 0.81 | 0.75 | 1.46 |
| 9 | Small Communications | 800 | .16 | 0.89 | 0.83 | 1.29 |
| 10 | Small Communications | 9 | .53 | 0.87 | 0.79 | 1.35 |
| 11 | Small Special Purpose | 30 | .48 | 0.78 | 0.73 | 1.49 |
| 12 | Large Data Management | 16 | .02 | 0.80 | 0.85 | 1.36 |
| 13 | Medium Search | 50 | .35 | 0.89 | 0.83 | 1.28 |
| 14 | Medium Data Management | 8 | .80 | 0.83 | 0.77 | 1.41 |
| 15 | Small Guidance and Control | 3325 | .20 | 0.80 | 0.76 | 1.42 |

Table 2-3b

Total Processor Life Cycle Cost vs. CFA for 1976 and 1985 Procurements

($\$ \times 10^6$)

| Sys. # | SYSTEM MISSION | 1976 Procurement INTER-DATA 8/32 | 1976 Procurement DEC PDP-11 | 1976 Procurement IBM S370 | 1985 Procurement INTER-DATA 8/32 | 1985 Procurement DEC PDP-11 | 1985 Procurement IBM S370 |
|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 24.9 | 26.2 | 29.9 | 2.49 | 2.62 | 2.99 |
| 2 | Medium Command and Control | 1.8 | 1.8 | 2.3 | .18 | .18 | .23 |
| 3 | Small Search | 11.8 | 11.4 | 13.9 | 1.18 | 1.14 | 1.39 |
| 4 | Large Command and Control | 10.7 | 10.7 | 13.6 | 1.07 | 1.07 | 1.36 |
| 5 | Medium Command and Control | 5.6 | 5.5 | 7.0 | .56 | .55 | .70 |
| 6 | Large Command and Control | 2.4 | 2.4 | 3.0 | .24 | .24 | .30 |
| 7 | Small Command and Control | 84.2 | 84.2 | 109.0 | 8.42 | 8.42 | 10.90 |
| 8 | Large Communications | 35.9 | 34.8 | 45.5 | 3.59 | 3.48 | 4.55 |
| 9 | Small Communications | 46.2 | 44.9 | 53.6 | 4.62 | 4.49 | 5.36 |
| 10 | Small Communications | .8 | .8 | 1.0 | .08 | .08 | .10 |
| 11 | Small Special Purpose | 2.6 | 2.5 | 3.3 | .26 | .25 | .33 |
| 12 | Large Data Management | .4 | .4 | .5 | .04 | .04 | .05 |
| 13 | Medium Search | 4.0 | 3.8 | 4.6 | .40 | .38 | .46 |
| 14 | Medium Data Management | .9 | .8 | 1.0 | .09 | .08 | .10 |
| 15 | Small Guidance and Control | 201.3 | 197.2 | 253.2 | 20.13 | 19.72 | 25.32 |

Table 2-3c
Unit Processor Life Cycle Cost vs CFA
for
1976 and 1985 Procurements

| SYS. # | SYSTEM MISSION | # UNIT $n_i$ | UNIT COST ($K) 1976 Procurement 8/32 | PDP-11 | S/370 | 1985 Procurement 8/32 | PDP-11 | S/370 |
|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 129.7 | 1365 | 155.7 | 13.0 | 13.6 | 15.6 |
| 2 | Medium Command and Control | 27 | 66.7 | 66.7 | 85.2 | 6.7 | 6.7 | 8.5 |
| 3 | Small Search | 100 | 118.0 | 114.0 | 139.0 | 11.8 | 11.4 | 13.9 |
| 4 | Large Command and Control | 178 | 60.1 | 60.1 | 76.4 | 6.0 | 6.0 | 7.6 |
| 5 | Medium Command and Control | 64 | 87.5 | 85.9 | 109.4 | 8.8 | 8.6 | 10.9 |
| 6 | Large Command and Control | 30 | 80.0 | 80.0 | 100.0 | 8.0 | 8.0 | 10.0 |
| 7 | Small Command and Control | 832 | 101.2 | 101.2 | 131.0 | 10.1 | 10.1 | 13.1 |
| 8 | Large Communications | 616 | 58.3 | 56.5 | 73.9 | 5.8 | 5.6 | 7.4 |
| 9 | Small Communications | 800 | 57.8 | 56.1 | 67.0 | 5.8 | 5.6 | 6.7 |
| 10 | Small Communications | 9 | 88.9 | 88.9 | 111.1 | 8.9 | 8.9 | 11.1 |
| 11 | Small Special Purpose | 30 | 86.7 | 83.3 | 110.0 | 8.7 | 8.3 | 11.0 |
| 12 | Large Data Management | 16 | 25.0 | 25.0 | 31.2 | 2.5 | 2.5 | 3.1 |
| 13 | Medium Search | 50 | 80.0 | 76.0 | 92.0 | 8.0 | 7.6 | 9.2 |
| 14 | Medium Data Management | 8 | 112.5 | 100.0 | 125.0 | 11.2 | 10.0 | 12.5 |
| 15 | Small Guidance and Control | 3325 | 60.5 | 59.3 | 76.2 | 6.0 | 5.9 | 7.6 |
| | Total of Unit Costs | | 1212.9 | 1189.5 | 1483.1 | 121.3 | 119.0 | 148.3 |
| | Average Unit Cost | | 80.9 | 79.3 | 98.9 | 8.1 | 7.9 | 9.9 |
| | % Relative to Average | | (6.4) | (8.2) | 14.5 | | | |

Table 2-4a

Main Memory Life Cycle Cost Parameters

| Sys. # | System Mission | # Units $n_i$ | Program Memory $PM_i$* | Data Memory $DM_i$* | Static Storage Ratio, $b_j$ INTER-DATA 8/32 | DEC PDP-11 | IBM S370 |
|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | .414 | .101 | 0.84 | 0.93 | 1.21 |
| 2 | Medium Command and Control | 27 | 1.638 | .412 | 0.86 | 0.85 | 1.30 |
| 3 | Small Search | 100 | .512 | .128 | 0.88 | 0.83 | 1.28 |
| 4 | Large Command and Control | 178 | 13.600 | 3.400 | 0.81 | 0.81 | 1.38 |
| 5 | Medium Command and Control | 64 | 1.600 | .400 | 0.85 | 0.82 | 1.32 |
| 6 | Large Command and Control | 30 | 3.321 | .830 | 0.84 | 0.84 | 1.32 |
| 7 | Small Command and Control | 832 | .618 | .152 | 0.81 | 0.82 | 1.37 |
| 8 | Large Communications | 616 | 3.200 | .800 | 0.84 | 0.80 | 1.37 |
| 9 | Small Communications | 800 | .116 | .031 | 0.95 | 0.86 | 1.19 |
| 10 | Small Communications | 9 | .408 | .102 | 0.90 | 0.82 | 1.29 |
| 11 | Small Special Purpose | 30 | .328 | .082 | 0.83 | 0.78 | 1.39 |
| 12 | Large Data Management | 16 | 1.600 | .400 | 0.83 | 0.85 | 1.32 |
| 13 | Medium Search | 50 | 3.712 | .928 | 0.92 | 0.88 | 1.21 |
| 14 | Medium Data Management | 8 | 3.200 | .800 | .84 | 0.79 | 1.37 |
| 15 | Small Guidance and Control | 3325 | .006 | .002 | 0.86 | 0.82 | 1.32 |

* Values in megabits

Table 2-4b

Total Main Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

($ x $10^6$)

| Sys. # | SYSTEM MISSION | 1976 Procurement INTER-DATA 8/32 | DEC PDP-11 | IBM S370 | 1985 Procurement INTER-DATA 8/32 | DEC PDP-11 | IBM S370 |
|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 6.89 | 7.47 | 9.44 | 0.69 | 0.75 | 0.94 |
| 2 | Medium Command and Control | 3.93 | 3.90 | 5.49 | 0.39 | 0.39 | 0.55 |
| 3 | Small Search | 4.63 | 4.42 | 6.27 | 0.46 | 0.44 | 0.63 |
| 4 | Large Command and Control | 205.28 | 205.28 | 315.67 | 20.53 | 20.53 | 31.57 |
| 5 | Medium Command and Control | 9.01 | 8.77 | 12.86 | 0.90 | 0.88 | 1.29 |
| 6 | Large Command and Control | 8.69 | 8.69 | 12.51 | 0.87 | 0.87 | 1.25 |
| 7 | Small Command and Control | 43.44 | 43.85 | 66.47 | 4.34 | 4.39 | 6.65 |
| 8 | Large Communications | 171.89 | 165.58 | 255.47 | 17.19 | 16.56 | 25.55 |
| 9 | Small Communications | 9.04 | 8.37 | 10.82 | 0.90 | 0.84 | 1.08 |
| 10 | Small Communications | 0.34 | 0.31 | 0.45 | 0.03 | 0.03 | 0.46 |
| 11 | Small Special Purpose | 2.62 | 2.58 | 3.06 | 0.26 | 0.26 | 0.31 |
| 12 | Large Data Management | 2.21 | 2.25 | 3.22 | 0.22 | 0.26 | 0.32 |
| 13 | Medium Search | 17.37 | 16.78 | 21.68 | 1.74 | 1.68 | 2.17 |
| 14 | Medium Data Management | 2.23 | 2.13 | 3.32 | 0.22 | 0.21 | 0.33 |
| 15 | Small Guidance and Control | 1.90 | 1.84 | 2.64 | 0.19 | 0.18 | 0.26 |

Table 2-4c
Unit Main Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

| SYS. # | SYSTEM MISSION | # UNIT $n_i$ | UNIT COST ($K) 1976 Procurement 8/32 | PDP-11 | S/370 | 1985 Procurement 8/32 | PDP-11 | S/370 |
|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 35.9 | 38.9 | 49.2 | 3.6 | 3.9 | 4.9 |
| 2 | Medium Command and Control | 27 | 145.6 | 144.4 | 203.3 | 14.6 | 14.4 | 20.3 |
| 3 | Small Search | 100 | 46.3 | 44.2 | 62.7 | 4.6 | 4.4 | 6.3 |
| 4 | Large Command and Control | 178 | 1153.3 | 1153.3 | 1173.4 | 115.3 | 115.3 | 117.3 |
| 5 | Medium Command and Control | 64 | 140.8 | 137.0 | 200.9 | 14.1 | 13.7 | 20.1 |
| 6 | Large Command and Control | 30 | 289.7 | 289.7 | 417.0 | 29.0 | 29.0 | 41.7 |
| 7 | Small Command and Control | 832 | 52.2 | 52.7 | 79.9 | 5.2 | 5.3 | 8.0 |
| 8 | Large Communications | 616 | 279.0 | 268.8 | 414.7 | 27.9 | 26.9 | 41.5 |
| 9 | Small Communications | 800 | 11.3 | 10.5 | 13.5 | 1.1 | 1.0 | 1.4 |
| 10 | Small Communications | 9 | 37.8 | 34.4 | 50.0 | 3.8 | 3.4 | 5.0 |
| 11 | Small Special Purpose | 30 | 87.3 | 86.0 | 102.0 | 8.7 | 8.6 | 10.2 |
| 12 | Large Data Management | 16 | 138.1 | 140.6 | 201.2 | 13.8 | 14.1 | 20.1 |
| 13 | Medium Search | 50 | 347.4 | 335.6 | 433.6 | 34.7 | 33.6 | 43.4 |
| 14 | Medium Data Management | 8 | 278.8 | 266.2 | 415.0 | 27.9 | 26.6 | 41.5 |
| 15 | Small Guidance and Control | 3325 | 0.6 | 0.6 | 0.8 | 0.1 | 0.1 | 0.1 |
| | Total of Unit Cost | | 3044.1 | 3022.9 | 4417.2 | 304.4 | 302.3 | 441.7 |
| | Average Unit Cost | | 202.9 | 200.2 | 294.5 | 20.3 | 20.0 | 29.4 |
| | % Relative to Average | | (12.7) | (13.9) | 26.6 | | | |

(4) Secondary Memory Life Cycle Cost

The parametric data required for secondary memory life cycle cost computation is shown in Table 2-5a. The total secondary memory life cycle cost for each system was computed as described in paragraph 2.3.3.4 and is shown in Table 2-5b. The unit secondary memory life cycle cost for each system is shown in Table 2-5c. The average unit secondary memory life cycle cost for all systems and architectures in 1976 is $3.4M. The costs using the PDP-11 and 8/32 architectures are 3.9% and 3.2% below the average while the cost using the IBM S/370 is 7.2% above the average.

(5) Total Hardware Life Cycle Cost

Tables 2-3b, 2-4b and 2-5b are summed to obtain the total hardware life cycle cost vs. CFA for 1976 and 1985 procurements. The result is shown in Table 2-6a. Table 2-6a indicates that the DEC PDP-11 and Interdata 8/32 architectures provide significantly lower hardware costs than the IBM S/370 architecture. The average hardware life cycle cost for all systems/architectures in 1976 is $1.75B. The costs using PDP-11 and 8/32 architectures are 8.7% and 7.7% below the average while the cost using the S/370 architecture is 16.4% above the average in 1976.

Tables 2-3c, 2-4c and 2-5c are summed to obtain the unit hardware life cycle cost vs. CFA for 1976 and 1985 procurements as shown in Table 2-6b. The average unit hardware life cycle cost for all systems/architectures in 1976 is $3.7M. The unit costs using the PDP-11 and 8/32 architectures are 4.7% and 3.9% below the average while the cost using the S/370 is 8.6% above the average in 1976.

(6) Applications Software Life Cycle Cost

To determine the applications software life cycle cost, it was necessary to derive the software tool availability index from the report of the Software Evaluation Methodology Subcommittee [WagnJ 76] for each CFA for 1976 and 1985; then, to compute the cost per applications software instruction.

As a baseline for the computation of the applications software life cycle cost in accordance with paragraph 2.3.3.5, the median cost curve shown in Figure 2-2 was employed. At the average TAI of 52%, this curve indicates a cost per instruction of $17, for 1976. The cost per instruction for the 3 CFA finalists in 1976 was estimated at $24, $18, and $12 for Interdata 8/32, DEC PDP-11 and IBM S/370, based upon TAI values of 34%, 50% and 73%, respectively. The corresponding values for 1985 were computed by assuming an annual expenditure of $2M to augment the support software base of the selected CFA. The resulting TAI values in 1985 are 83%, 100% and 100% corresponding to cost per instruction of $10, $7.50 and $7.50 for Interdata 8/32 DEC PDP-11 and IBM S/370, respectively. This data was then employed to compute applications software life cycle cost for each of the 15 systems under consideration, for each CFA and for 1976 and 1985. The resulting life cycle costs are shown in Table 2-7 assuming an annual support software expenditure of $2M. This table indicates that the average applications software life cycle cost in 1976 for all systems/architectures is $162M. The cost using the PDP-11 is approximately equal to the average while the costs using 8/32 and S/370 are 33% above and 33% below the average respectively in 1976.

In 1985, the average software life cycle cost is reduced to $75M. The cost using the PDP-11 and S/370 are 9.7% below the average while the cost using the 8/32 is 19% above the average in 1985.

Table 2-5a

Secondary Memory Life Cycle Cost Parameters

| Sys. # | SYSTEM MISSION | # Units $n_i$ | Program Memory $PM_i$ * | Data Memory $DM_i$ * | Static Storage Ratio, $b_j$ INTER-DATA 8/32 | DEC PDP-11 | IBM S370 |
|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 1.9 | 7.7 | 0.84 | 0.93 | 1.24 |
| 2 | Medium Command and Control | 27 | 2.2 | 8.8 | 0.86 | 0.85 | 1.30 |
| 3 | Small Search | 100 | 2.8 | 11.2 | 0.88 | 0.83 | 1.28 |
| 4 | Large Command and Control | 178 | 4.0 | 16.0 | 0.81 | 0.81 | 1.38 |
| 5 | Medium Command and Control | 64 | 15.8 | 63.2 | 0.85 | 0.82 | 1.32 |
| 6 | Large Command and Control | 30 | 8.4 | 33.6 | 0.84 | 0.84 | 1.32 |
| 7 | Small Command and Control | 832 | .4 | 1.6 | 0.81 | 0.82 | 1.37 |
| 8 | Large Communications | 616 | 13.0 | 52.0 | 0.84 | 0.80 | 1.37 |
| 9 | Small Communications | 800 | 0 | 0 | 0.95 | 0.86 | 1.19 |
| 10 | Small Communications | 9 | 3.2 | 12.8 | 0.90 | 0.82 | 1.29 |
| 11 | Small Special Purpose | 30 | .1 | .3 | 0.83 | 0.78 | 1.39 |
| 12 | Large Data Management | 16 | 573.4 | 2293.6 | 0.83 | 0.85 | 1.32 |
| 13 | Medium Search | 50 | 3.2 | 12.8 | 0.92 | 0.88 | 1.21 |
| 14 | Medium Data Management | 8 | 1912.0 | 7648.0 | 0.84 | 0.79 | 1.37 |
| 15 | Small Guidance and Control | 3325 | 0 | 0 | 0.86 | 0.82 | 1.32 |

* Values in megabits

Table 2-5b

Total Secondary Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements
($\$ \times 10^6$)

| Sys. # | SYSTEM MISSION | 1976 Procurement INTER-DATA 8/32 | 1976 Procurement DEC PDP-11 | 1976 Procurement IBM S370 | 1985 Procurement INTER-DATA 8/32 | 1985 Procurement DEC PDP-11 | 1985 Procurement IBM S370 |
|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 7.14 | 7.27 | 7.72 | 0.71 | 0.73 | 0.77 |
| 2 | Medium Command and Control | 1.15 | 1.15 | 1.26 | 0.11 | 0.11 | 0.13 |
| 3 | Small Search | 5.46 | 5.41 | 5.91 | 0.55 | 0.54 | 0.59 |
| 4 | Large Command and Control | 13.70 | 13.70 | 15.32 | 1.37 | 1.37 | 1.53 |
| 5 | Medium Command and Control | 19.61 | 19.50 | 21.52 | 1.96 | 1.95 | 2.15 |
| 6 | Large Command and Control | 4.88 | 4.88 | 5.86 | 0.49 | 0.49 | 0.59 |
| 7 | Small Command and Control | 6.40 | 6.41 | 7.65 | 0.64 | 0.64 | 0.76 |
| 8 | Large Communications | 155.03 | 153.75 | 172.01 | 15.50 | 15.37 | 17.20 |
| 9 | Small Communications | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | Small Communications | .56 | .55 | .61 | 0.06 | 0.06 | 0.06 |
| 11 | Small Special Purpose | .04 | .04 | .05 | 0 | 0 | 0 |
| 12 | Large Data Management | 177.25 | 177.98 | 195.23 | 17.72 | 17.80 | 19.52 |
| 13 | Medium Search | 3.15 | 3.12 | 3.38 | 0.31 | 0.31 | 0.34 |
| 14 | Medium Data Management | 296.13 | 293.07 | 328.56 | 29.61 | 29.61 | 32.86 |
| 15 | Small Guidance and Control | 0 | 0 | 0 | 0 | 0 | 0 |

Table 2-5c
Unit Secondary Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

| SYS. # | SYSTEM MISSION | # UNIT $n_i$ | UNIT COST ($K) 1976 Procurement 8/32 | PDP-11 | S/370 | 1985 Procurement 8/32 | PDP-11 | S/370 |
|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 37.2 | 37.9 | 40.2 | 3.7 | 3.8 | 4.0 |
| 2 | Medium Command and Control | 27 | 42.6 | 42.6 | 46.7 | 4.3 | 4.3 | 4.7 |
| 3 | Small Search | 100 | 54.6 | 54.1 | 59.1 | 5.5 | 5.4 | 5.9 |
| 4 | Large Command and Control | 178 | 77.0 | 77.0 | 86.1 | 7.7 | 7.7 | 8.6 |
| 5 | Medium Command and Control | 64 | 306.4 | 304.6 | 336.2 | 30.6 | 30.5 | 33.6 |
| 6 | Large Command and Control | 30 | 162.7 | 162.7 | 195.3 | 16.3 | 16.3 | 19.5 |
| 7 | Small Command and Control | 832 | 7.7 | 7.7 | 9.2 | 0.8 | 0.8 | 0.9 |
| 8 | Large Communications | 616 | 251.7 | 249.6 | 279.2 | 25.2 | 25.0 | 27.9 |
| 9 | Small Communications | 800 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | Small Communications | 9 | 62.2 | 61.1 | 67.8 | 6.2 | 6.1 | 6.8 |
| 11 | Small Special Purpose | 30 | 1.3 | 1.3 | 1.7 | 0.1 | 0.1 | 0.2 |
| 12 | Large Data Management | 16 | 11078.1 | 11123.8 | 12201.9 | 1107.8 | 1112.4 | 1220.2 |
| 13 | Medium Search | 50 | 63.0 | 62.4 | 67.6 | 6.3 | 6.2 | 6.8 |
| 14 | Medium Data Management | 8 | 37016.2 | 36633.8 | 41070.0 | 3701.6 | 3663.4 | 4107.0 |
| 15 | Small Guidance and Control | 3325 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total of Unit Cost | | 49160.7 | 48818.6 | 54461.0 | 4916.1 | 4881.9 | 5446.1 |
| | Average Unit Cost | | 3277.4 | 3254.6 | 3630.7 | 327.7 | 325.5 | 363.1 |
| | % Relative to Average | | (3.2) | (3.9) | 7.2 | | | |

Table 2-6a

Total Hardware Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

($\$ \times 10^6$)

| Sys. # | SYSTEM MISSION | 1976 Procurement INTER-DATA 8/32 | 1976 Procurement DEC PDP-11 | 1976 Procurement IBM S370 | 1985 Procurement INTER-DATA 8/32 | 1985 Procurement DEC PDP-11 | 1985 Procurement IBM S370 |
|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 38.9 | 40.9 | 47.1 | 3.9 | 4.1 | 4.7 |
| 2 | Medium Command and Control | 6.9 | 6.9 | 9.1 | 0.7 | 0.7 | 0.9 |
| 3 | Small Search | 21.9 | 21.2 | 26.1 | 2.2 | 2.1 | 2.6 |
| 4 | Large Command and Control | 229.7 | 229.7 | 344.60 | 23.0 | 23.0 | 34.5 |
| 5 | Medium Command and Control | 34.2 | 33.8 | 41.4 | 3.4 | 3.4 | 4.1 |
| 6 | Large Command and Control | 16.0 | 16.0 | 21.4 | 1.6 | 1.6 | 2.1 |
| 7 | Small Command and Control | 134.0 | 134.5 | 183.1 | 13.4 | 13.4 | 18.3 |
| 8 | Large Communications | 362.8 | 354.1 | 473.0 | 36.3 | 35.4 | 47.3 |
| 9 | Small Communications | 55.2 | 53.3 | 64.4 | 5.5 | 5.3 | 6.4 |
| 10 | Small Communications | 1.7 | 1.7 | 2.1 | .2 | .2 | .2 |
| 11 | Small Special Purpose | 5.3 | 5.1 | 6.4 | .5 | .5 | .6 |
| 12 | Large Data Management | 179.9 | 180.6 | 199.0 | 18.0 | 18.1 | 19.9 |
| 13 | Medium Search | 24.5 | 23.7 | 29.7 | 2.4 | 2.4 | 3.0 |
| 14 | Medium Data Management | 299.3 | 296.0 | 332.9 | 29.9 | 29.6 | 33.3 |
| 15 | Small Guidance and Control | 203.2 | 199.0 | 255.8 | 20.3 | 19.9 | 25.6 |
| | Total Cost | 1614 | 1597 | 2036 | 161.3 | 159.7 | 203.5 |
| | % Relative to Average | (7.7) | (8.7) | 16.4 | | | |

Table 2-6b
Unit Hardware Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

| SYS. # | SYSTEM MISSION | # UNIT $n_i$ | UNIT COST ($K) 1976 Procurement 8/32 | PDP-11 | S/370 | 1985 Procurement 8/32 | PDP-11 | S/370 |
|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 202.8 | 213.5 | 245.1 | 20.3 | 21.3 | 24.5 |
| 2 | Medium Command and Control | 27 | 254.9 | 253.7 | 335.2 | 25.5 | 25.4 | 33.5 |
| 3 | Small Search | 100 | 218.9 | 212.3 | 260.8 | 21.9 | 21.2 | 26.1 |
| 4 | Large Command and Control | 178 | 1290.4 | 1290.4 | 1936.0 | 129.0 | 129.0 | 193.6 |
| 5 | Medium Command and Control | 64 | 534.4 | 528.1 | 646.9 | 53.4 | 52.8 | 64.7 |
| 6 | Large Command and Control | 30 | 533.3 | 533.3 | 713.3 | 53.3 | 53.3 | 71.3 |
| 7 | Small Command and Control | 832 | 161.7 | 161.7 | 220.1 | 16.1 | 16.2 | 22.0 |
| 8 | Large Communications | 616 | 589.0 | 574.8 | 767.9 | 58.9 | 57.5 | 76.8 |
| 9 | Small Communications | 800 | 69.0 | 66.6 | 80.5 | 6.9 | 6.7 | 8.0 |
| 10 | Small Communications | 9 | 188.9 | 188.9 | 233.3 | 18.9 | 18.9 | 23.3 |
| 11 | Small Special Purpose | 30 | 176.7 | 170.0 | 213.3 | 17.7 | 17.0 | 21.3 |
| 12 | Large Data Management | 16 | 11243.8 | 11287.5 | 12437.5 | 1124.4 | 1128.8 | 1143.8 |
| 13 | Medium Search | 50 | 490.0 | 474.0 | 594.0 | 49.0 | 47.4 | 59.4 |
| 14 | Medium Data Management | 8 | 37412.5 | 37000.0 | 41612.5 | 3741.2 | 3700.0 | 4161.2 |
| 15 | Small Guidance and Control | 3325 | 61.1 | 59.8 | 76.9 | 6.1 | 6.1 | 7.7 |
| | Total of Unit Costs | | 53427 | 53014 | 60373 | 5343 | 5301 | 6037 |
| | Average Unit Cost | | 3562 | 3534 | 4025 | 356 | 353 | 402 |
| | % Relative to Average | | (3.9) | (4.7) | 8.6 | | | |

Table 2-7

Applications Software Life Cycle Cost vs. CFA
Assuming Software Tool Expenditure of $2M/Yr

($\$ \times 10^6$)

| SYS. # | SYSTEM MISSION | 1976 Procurement INTER-DATA 8/32 | DEC PDP-11 | IBM S370 | 1985 Procurement INTER-DATA 8/32 | DEC PDP-11 | IBM S370 |
|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 4.22 | 3.17 | 2.11 | 1.76 | 1.32 | 1.32 |
| 2 | Medium Command and Control | 19.01 | 14.26 | 9.50 | 7.92 | 5.94 | 5.94 |
| 3 | Small Search | 2.64 | 1.98 | 1.32 | 1.10 | .83 | .83 |
| 4 | Large Command and Control | 49.50 | 37.13 | 24.75 | 20.63 | 15.47 | 15.47 |
| 5 | Medium Command and Control | 6.20 | 4.65 | 3.10 | 2.59 | 1.94 | 1.94 |
| 6 | Large Command and Control | 33.00 | 24.75 | 16.50 | 13.75 | 10.31 | 10.31 |
| 7 | Small Command and Control | 13.20 | 9.90 | 6.60 | 5.50 | 4.13 | 4.13 |
| 8 | Large Communications | 23.10 | 17.33 | 11.55 | 9.63 | 7.33 | 7.22 |
| 9 | Small Communications | 1.06 | .79 | .53 | .44 | .33 | .33 |
| 10 | Small Communications | 10.96 | 8.22 | 5.48 | 4.57 | 3.42 | 3.42 |
| 11 | Small Special Purpose | 1.85 | 1.39 | .92 | .77 | .58 | .58 |
| 12 | Large Data Management | 42.77 | 32.08 | 21.38 | 17.82 | 13.37 | 13.37 |
| 13 | Medium Search | 3.70 | 2.77 | 1.85 | 1.54 | 1.16 | 1.16 |
| 14 | Medium Data Management | 4.62 | 3.47 | 2.31 | 1.92 | 1.44 | 1.44 |
| 15 | Small Guidance and Control | .13 | .10 | .07 | .06 | .04 | .04 |
| | Total Cost | 216 | 162 | 108 | 90 | 68 | 68 |
| | % Relative to Average | 33 | - | (33) | 19 | (9.7) | (9.7) |

(7) Total Life Cycle Cost vs. CFA

Table 2-8a displays, in a single chart, the comparison of total life cycle costs for each of the three architectures for 1976. Table 2-8b presents the same information for 1985. Circled values indicate the least cost architecture for a particular system and the least total cost for implementing all fifteen systems. The number of times an architecture is thus selected is also totaled and shown at the bottom of the chart as the Number of System Preferences. Table 2-8a indicates that:

(a.) In 1976, the DEC PDP-11, IBM S/370 and Interdata 8/32 would have been selected for 11, 3 and 1 systems, respectively, on a life cycle cost basis. The average total life cycle cost for all systems/architectures in 1976 is \$1.91B. The PDP-11 and 8/32 costs are comparable being 8.0% and 4.2%, respectively below the average. The S/370 cost is 12.2% above the average or 20.2% above the PDP-11 cost.

(b.) In 1985, (Table 2-8b) the system preferences for DEC, IBM and Interdata would be 14.5, 0.5 and none, respectively. The average total life cycle cost for all systems/architectures is \$250M in 1985. The 8/32 cost is approximately equal to the average cost while the PDP-11 and S/370 costs are 8.9% below and 8.7% above, respectively, the average cost.

(8) Sensitivity Analysis

The results shown in Tables 2-8a and 2-8b are based upon the following parametric values:

(a.) Cost per Instruction. The use of the median curve in Figure 2-2 for estimating the cost per applications software instruction as a function of TAI. This curve yields an average cost per instruction of \$17 in 1976 for the three CFA finalists. This value corresponds to an average hardware:software life cycle cost ratio of 12:1 and 2.4:1 in 1976 and 1985, respectively, as shown in Table 2-9.

(b.) Support Software Investment Rate. The data presented thus far reflects the use of \$2M per year to augment the support software base. Table 2-10 indicates the impact of alternate investment rates of \$1M and \$3M annually upon the 1985 cost per instruction.

(c.) Weighted S, M and R Values. The architecture measures of effectiveness (S, M and R) are weighted for each system application as described in the Appendix, Section 2.7.

The above parametric values were perturbed in order to determine the sensitivity of the life cycle cost model. The results are described in the following subparagraphs.

(9) Instruction Cost Sensitivity

The average cost per instruction in 1976 was doubled to $34, or $9 in excess of the worst-case curve in Figure 2-1. The resulting hardware:software ratios are 6:1 and 1.2:1 in 1976 and 1985 respectively, as shown in Table 2-9. The resulting life cycle costs for 1976 and 1985 are depicted in Tables 2-11a and 2-11b, respectively. These tables indicate that in terms of the comparative costs of the three architectures, the model is relatively insensitive to doubling the cost per applications software instruction. Comparing Tables 2-8a and 2-11a, IBM is shown to pick up one system implementation at both DEC and Interdata expense in 1976 so that DEC, IBM and Interdata architectures would be preferred in 10.5, 4.0 and 0.5 systems, respectively. The DEC architecture remains the lowest in total life cycle cost for all systems. For 1985, comparing Tables 2-8b and 2-11b shows no change with DEC architecture being preferred in 14.5 systems.

(10) Support-Software Investment-Rate Sensitivity

The data examined thus far for 1985 reflect an investment in the software bases of the three architectures of $2M annually.

The data for 1985 were re-examined to determine the impact of reducing the investment in the software base to $1M annually for two different situations, i.e., for the basic cost per instruction of application software and then double the basic cost. The data are summarized in Tables 2-12a and 2-12b, respectively. Table 2-12a shows that the selection of IBM would increase to 5 systems while DEC would drop to 10. This is also predictable since at a $1M per year investment rate in the software base IBM retains for a longer time its cost advantage in producing application software. At this lower investment rate, Table 2-10 shows that while IBM has achieved the ideal support software set, DEC has only 63% while Interdata has 61%.

Doubling the cost per application software instruction merely extends a software favorable situation as shown in Table 2-12b. In this table, IBM selections equal DEC selections at seven.

(11) Sensitivity to Unweighted S, M, and R Values

The data presented in the report uses weighted values of the S, M, and R data resulting from test program runs and provided by Carnegie Mellon University. The weights and the calculations are discussed in some detail in the Appendix, Section 2.7.

The data was re-examined to determine the impact if the S, M, and R measures were used without the discriminating weights applied. The results are displayed in Table 2-13 and show that, for 1985, the model is relatively insensitive to the weighting factors applied to the S, M, and R values. At $17 per application software instruction a few systems shift from DEC to Interdata; at $34 per instruction a few systems shift from DEC to IBM. DEC remains predominant. However, for 1975, the Interdata gains the low-cost position for unweighted S, M, & R.

(12)Summary of Perturbations

In subparagraphs 2.4.9 to 2.4.11, we have re-examined the bottom up model to determine its sensitivity to several key parameters. The results are summarized in Table 2-14 which shows the impact on the number of times an architecture would be selected to implement the fifteen Army systems for each of the

TABLE 2-8a

Total Life Cycle Cost vs CFA

1976 Procurement

1976 AVERAGE APPL'N SW COST = $17/INSTRUCTION

| SYS # | SYSTEM MISSION | $n_i$ | INTERDATA 8/32 HDW | INTERDATA 8/32 ASW | INTERDATA 8/32 TOTAL | DEC PDP-11 HDW | DEC PDP-11 ASW | DEC PDP-11 TOTAL | IBM S370 HDW | IBM S370 ASW | IBM S370 TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 38.9 | 4.2 | 43.1 | 40.9 | 3.2 | 44.1 | 47.1 | 2.1 | 49.2 |
| 2 | Medium Command and Control | 27 | 6.9 | 19.0 | 25.9 | 6.9 | 14.3 | 21.2 | 9.1 | 9.5 | 18.6 |
| 3 | Small Search | 100 | 21.9 | 2.6 | 24.5 | 21.2 | 2.0 | 23.2 | 26.1 | 1.3 | 29.4 |
| 4 | Large Command and Control | 178 | 230.0 | 49.5 | 280.0 | 229.0 | 37.1 | 267.0 | 345.0 | 24.8 | 369.0 |
| 5 | Medium Command and Control | 64 | 34.2 | 6.2 | 40.4 | 33.8 | 4.7 | 38.5 | 41.4 | 3.1 | 44.5 |
| 6 | Large Command and Control | 30 | 16.0 | 33.0 | 49.0 | 16.0 | 24.8 | 40.8 | 21.4 | 16.5 | 37.9 |
| 7 | Small Command and Control | 832 | 134.0 | 13.2 | 147.0 | 135.0 | 9.9 | 144.0 | 183.0 | 6.6 | 190.0 |
| 8 | Large Communications | 616 | 363.0 | 23.1 | 386.0 | 354.0 | 17.3 | 371.0 | 473.0 | 11.6 | 485.0 |
| 9 | Small Communications | 800 | 55.2 | 1.1 | 56.3 | 53.3 | 0.8 | 54.1 | 64.4 | 0.5 | 64.9 |
| 10 | Small Communications | 9 | 1.7 | 11.0 | 12.7 | 1.7 | 8.2 | 9.9 | 2.1 | 5.5 | 7.6 |
| 11 | Small Special Purpose | 30 | 5.3 | 1.9 | 7.1 | 5.1 | 1.4 | 6.5 | 6.4 | 0.9 | 7.3 |
| 12 | Large Data Management | 16 | 180.0 | 42.8 | 223.0 | 181.0 | 32.0 | 213.0 | 199.0 | 21.4 | 220.0 |
| 13 | Medium Search | 50 | 24.5 | 3.7 | 28.2 | 23.7 | 2.8 | 26.5 | 29.7 | 1.9 | 31.5 |
| 14 | Medium Data Management | 8 | 299.0 | 4.6 | 304.0 | 296.0 | 3.5 | 300.0 | 333.0 | 2.3 | 335.0 |
| 15 | Small Guidance and Control | 3325 | 203.0 | 0.1 | 203.0 | 199.0 | 0.1 | 199.0 | 256.0 | 0.1 | 256.0 |
| | Total Cost | | 1614 | 216 | 1830 | 1596 | 162 | 1758 | 2037 | 108 | 2145 |
| | # System Preferences | | | | 1.0 | | | 11 | | | 3.0 |

TABLE 2-8b

Total Life Cycle Cost vs CFA

1985 Procurement and Software Tool Expenditure of $2M/yr

1976 Average Appl'n SW Cost = $17/Instruction

| SYS # | SYSTEM MISSION | $n_i$ | INTERDATA 8/32 HDW | INTERDATA 8/32 ASW | INTERDATA 8/32 TOTAL | DEC PDP-11 HDW | DEC PDP-11 ASW | DEC PDP-11 TOTAL | IBM S370 HDW | IBM S370 ASW | IBM S370 TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 3.9 | 1.8 | 5.7 | 4.1 | 1.3 | 5.4 | 4.7 | 1.3 | 6.0 |
| 2 | Medium Command and Control | 27 | 0.7 | 7.9 | 8.6 | 0.7 | 5.9 | 6.6 | 0.9 | 5.9 | 6.8 |
| 3 | Small Search | 100 | 2.2 | 1.1 | 3.3 | 2.1 | 0.8 | 2.9 | 2.6 | 0.8 | 3.4 |
| 4 | Large Command and Control | 178 | 23.0 | 20.6 | 43.6 | 23.0 | 15.5 | 38.5 | 34.5 | 15.5 | 50.0 |
| 5 | Medium Command and Control | 64 | 3.4 | 2.6 | 6.0 | 3.4 | 1.9 | 5.3 | 4.1 | 1.9 | 6.0 |
| 6 | Large Command and Control | 30 | 1.6 | 13.8 | 15.4 | 1.6 | 10.3 | 11.9 | 2.1 | 10.3 | 12.4 |
| 7 | Small Command and Control | 832 | 13.4 | 5.5 | 18.9 | 13.4 | 4.1 | 17.5 | 18.3 | 4.1 | 22.4 |
| 8 | Large Communications | 616 | 36.3 | 9.6 | 45.9 | 35.4 | 7.3 | 42.7 | 47.3 | 7.2 | 54.5 |
| 9 | Small Communications | 800 | 5.5 | 0.4 | 5.9 | 5.3 | 0.3 | 5.6 | 6.4 | 0.3 | 6.7 |
| 10 | Small Communications | 9 | 0.2 | 4.6 | 4.8 | 0.2 | 3.4 | 3.6 | 0.2 | 3.4 | 3.6 |
| 11 | Small Special Purpose | 30 | 0.5 | 0.8 | 1.3 | 12.5 | 0.6 | 1.1 | 0.6 | 0.6 | 1.2 |
| 12 | Large Data Management | 16 | 18.0 | 17.8 | 35.8 | 18.1 | 13.4 | 31.5 | 19.9 | 13.4 | 33.3 |
| 13 | Medium Search | 50 | 2.4 | 1.5 | 3.9 | 2.4 | 1.2 | 3.6 | 3.0 | 1.2 | 4.2 |
| 14 | Medium Data Management | 8 | 29.9 | 1.9 | 31.8 | 29.6 | 1.4 | 31.0 | 33.3 | 1.4 | 34.7 |
| 15 | Small Guidance and Control | 3325 | 20.3 | 0.1 | 20.4 | 19.9 | 0.1 | 20.0 | 25.6 | 0.1 | 25.7 |
| | Total Cost | | 161 | 90 | 251 | 160 | 68 | 228 | 204 | 68 | 272 |
| | # System Preferences | | | | - | | | 14.5 | | | 0.5 |

Table 2-9

Hardware:Software Ratios

BOTTOM-UP LIFE CYCLE COST MODEL

| CFA | 1976 AVG APPL'N SW COST = $17/I | | 1976 AVG APPL'N SW COST = $34/I | |
|---|---|---|---|---|
| | 1976 PROC. | 1985 PROC. | 1976 PROC. | 1985 PROC. |
| INTERDATA 8/32 | 7.5 | 1.8 | 3.7 | 0.9 |
| DEC PDP-11 | 9.8 | 2.4 | 4.9 | 1.2 |
| IBM S370 | 18.9 | 3.0 | 9.4 | 1.5 |
| AVERAGE | 12 | 2.4 | 6.0 | 1.2 |

Table 2-10

Application Software Cost Per Instruction
vs
Support Software Investment Rate

A. Software Tool Availability Index

| Annual Support Software Investment $M | 1976 | | | 1985 | | |
|---|---|---|---|---|---|---|
| | INTERDATA 8/32 | DEC PDP-11 | IBM S370 | INTERDATA 8/32 | DEC PDP-11 | IBM S370 |
| 1 | .34 | .50 | .73 | 0.61 | 0.83 | 1.0 |
| 2 | .34 | .50 | .73 | 0.83 | 1.0 | 1.0 |
| 3 | .34 | .50 | .73 | 1.0 | 1.0 | 1.0 |

B. Applications Software Cost Per Instruction ($)

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 24.00 | 18.00 | 12.00 | 14.00 | 10.00 | 7.50 |
| 2 | 24.00 | 18.00 | 12.00 | 10.00 | 7.50 | 7.50 |
| 3 | 24.00 | 18.00 | 12.00 | 7.50 | 7.50 | 7.50 |

TABLE 2-11a

Total Life Cycle Cost vs CFA

1976 Procurement

1976 AVERAGE APPL'N SW COST = $34/INSTRUCTION

| SYS # | SYSTEM MISSION | $n_i$ | INTERDATA 8/32 HDW | INTERDATA 8/32 ASW | INTERDATA 8/32 TOTAL | DEC PDP-11 HDW | DEC PDP-11 ASW | DEC PDP-11 TOTAL | IBM S370 HDW | IBM S370 ASW | IBM S370 TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 38.9 | 8.4 | 47.3 | 40.9 | 6.4 | 47.3 | 47.1 | 4.2 | 51.3 |
| 2 | Medium Command and Control | 27 | 6.9 | 38.0 | 44.9 | 6.9 | 28.6 | 35.5 | 9.1 | 19.0 | 28.1 |
| 3 | Small Search | 100 | 21.9 | 5.2 | 27.1 | 21.2 | 4.0 | 25.2 | 26.1 | 2.6 | 20.7 |
| 4 | Large Command and Control | 178 | 230.0 | 99.0 | 330.0 | 229.0 | 74.2 | 304.0 | 345.0 | 49.6 | 394.0 |
| 5 | Medium Command and Control | 64 | 34.2 | 12.4 | 46.6 | 33.8 | 9.4 | 43.2 | 41.4 | 6.2 | 47.6 |
| 6 | Large Command and Control | 30 | 16.0 | 66.0 | 82.0 | 16.0 | 49.6 | 65.6 | 21.4 | 33.0 | 54.4 |
| 7 | Small Command and Control | 832 | 134.0 | 26.4 | 160.0 | 135.0 | 19.8 | 154.0 | 183.0 | 13.2 | 197.0 |
| 8 | Large Communications | 616 | 363.0 | 46.2 | 409.0 | 354.0 | 34.6 | 388.0 | 473.0 | 23.2 | 497.0 |
| 9 | Small Communications | 800 | 55.2 | 2.2 | 57.4 | 53.3 | 1.6 | 54.9 | 64.4 | 1.0 | 65.4 |
| 10 | Small Communications | 9 | 1.7 | 22.0 | 23.7 | 1.7 | 16.4 | 18.1 | 2.1 | 11.0 | 13.1 |
| 11 | Small Special Purpose | 30 | 5.3 | 3.8 | 9.0 | 5.1 | 2.8 | 7.9 | 6.4 | 1.8 | 8.2 |
| 12 | Large Data Management | 16 | 180.0 | 85.6 | 266.0 | 181.0 | 64.0 | 245.0 | 199.0 | 42.8 | 241.0 |
| 13 | Medium Search | 50 | 24.5 | 7.4 | 31.9 | 23.7 | 5.6 | 29.3 | 29.7 | 3.8 | 33.4 |
| 14 | Medium Data Management | 8 | 299.0 | 9.2 | 309.0 | 296.0 | 7.0 | 304.0 | 333.0 | 4.6 | 337.0 |
| 15 | Small Guidance and Control | 3325 | 203.0 | 0.2 | 203.0 | 199.0 | 0.2 | 199.0 | 256.0 | 0.2 | 256.0 |
| | Total Cost | | 1614 | 432 | 2046 | 1596 | 324 | 1920 | 2037 | 216 | 2253 |
| | # System Preferences | | | | 0.5 | | | 10.5 | | | 4.0 |

TABLE 2-11b

Total Life Cycle Cost vs CFA

1985 Procurement / $2M yr Support SW Expenditure

1976 Average Appl'n SW Cost = $34/Instruction

| SYS # | SYSTEM MISSION | $n_i$ | INTERDATA 8/32 HDW | INTERDATA 8/32 ASW | INTERDATA 8/32 TOTAL | DEC PDP-11 HDW | DEC PDP-11 ASW | DEC PDP-11 TOTAL | IBM S370 HDW | IBM S370 ASW | IBM S370 TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 3.9 | 3.6 | 7.5 | 4.1 | 2.6 | 6.7 | 4.7 | 2.6 | 7.3 |
| 2 | Medium Command and Control | 27 | 0.7 | 15.8 | 16.5 | 0.7 | 11.8 | 12.5 | 0.9 | 11.8 | 12.7 |
| 3 | Small Search | 100 | 2.2 | 2.2 | 4.4 | 2.1 | 1.6 | 3.7 | 2.6 | 1.6 | 4.2 |
| 4 | Large Command and Control | 178 | 23.0 | 41.2 | 64.2 | 23.0 | 31.0 | 54.0 | 34.5 | 31.0 | 65.5 |
| 5 | Medium Command and Control | 64 | 3.4 | 5.2 | 8.6 | 3.4 | 3.8 | 7.2 | 4.1 | 3.8 | 7.9 |
| 6 | Large Command and Control | 30 | 1.6 | 27.6 | 29.2 | 1.6 | 20.6 | 22.2 | 2.1 | 20.6 | 22.7 |
| 7 | Small Command and Control | 832 | 13.4 | 11.0 | 24.4 | 13.4 | 8.2 | 21.6 | 18.3 | 8.2 | 26.5 |
| 8 | Large Communications | 616 | 36.3 | 19.2 | 55.5 | 35.4 | 14.6 | 50.0 | 47.3 | 14.6 | 61.7 |
| 9 | Small Communications | 800 | 5.5 | 0.8 | 6.3 | 5.3 | 0.6 | 5.9 | 6.4 | 0.6 | 7.0 |
| 10 | Small Communications | 9 | 0.2 | 9.2 | 9.4 | 0.2 | 6.8 | 7.0 | 0.2 | 6.8 | 7.0 |
| 11 | Small Special Purpose | 30 | 0.5 | 1.6 | 2.1 | 0.5 | 1.2 | 1.7 | 0.6 | 1.2 | 1.8 |
| 12 | Large Data Management | 16 | 18.0 | 35.6 | 53.6 | 18.1 | 26.8 | 44.9 | 19.9 | 26.8 | 46.7 |
| 13 | Medium Search | 50 | 2.4 | 3.0 | 5.4 | 2.4 | 2.4 | 4.8 | 3.0 | 2.4 | 5.4 |
| 14 | Medium Data Management | 8 | 29.9 | 3.8 | 33.7 | 29.6 | 2.8 | 32.4 | 33.3 | 2.8 | 36.1 |
| 15 | Small Guidance and Control | 3325 | 20.3 | 0.2 | 20.5 | 19.9 | 0.2 | 20.1 | 25.6 | 0.2 | 25.8 |
| | Total Cost | | 161 | 180 | 341 | 160 | 136 | 2966 | 204 | 136 | 340 |
| | # System Preferences | | | | - | | | 14.5 | | | 0.5 |

TABLE 2-12a

Total Life Cycle Cost vs CFA ($ x $10^6$)

1985 Procurement and Software Tool Expenditure of $1M/yr

1976 Average Appl'n SW Cost = $17/Instruction

| SYS # | SYSTEM MISSION | $n_i$ | INTERDATA 8/32 HDW | INTERDATA 8/32 ASW | INTERDATA 8/32 TOTAL | DEC PDP-11 HDW | DEC PDP-11 ASW | DEC PDP-11 TOTAL | IBM S370 HDW | IBM S370 ASW | IBM S370 TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 3.9 | 2.5 | 6.4 | 4.1 | 1.8 | 5.9 | 4.7 | 1.3 | 6.0 |
| 2 | Medium Command and Control | 27 | 0.7 | 11.1 | 11.8 | 0.7 | 7.9 | 8.6 | 0.9 | 5.3 | 6.8 |
| 3 | Small Search | 100 | 2.2 | 1.5 | 3.7 | 2.1 | 1.1 | 3.2 | 2.6 | 0.8 | 3.4 |
| 4 | Large Command and Control | 178 | 23.0 | 28.9 | 51.9 | 23.0 | 20.6 | 43.6 | 34.5 | 15.5 | 50.0 |
| 5 | Medium Command and Control | 64 | 3.4 | 3.6 | 7.0 | 3.4 | 2.6 | 6.0 | 4.1 | 1.9 | 6.0 |
| 6 | Large Command and Control | 30 | 1.6 | 19.3 | 20.9 | 1.6 | 13.8 | 15.4 | 2.1 | 10.3 | 12.4 |
| 7 | Small Command and Control | 832 | 13.4 | 7.7 | 21.1 | 13.4 | 5.5 | 18.9 | 18.3 | 4.1 | 22.4 |
| 8 | Large Communications | 616 | 36.3 | 13.5 | 49.8 | 35.4 | 9.6 | 45.0 | 47.3 | 7.2 | 54.5 |
| 9 | Small Communications | 800 | 5.5 | 0.6 | 6.1 | 5.3 | 0.4 | 5.7 | 6.4 | 0.3 | 6.7 |
| 10 | Small Communications | 9 | 0.2 | 1.4 | 6.6 | 0.2 | 4.6 | 4.8 | 0.2 | 3.4 | 3.6 |
| 11 | Small Special Purpose | 30 | 0.5 | 1.1 | 1.6 | 0.5 | 0.7 | 1.2 | 0.6 | 0.6 | 1.2 |
| 12 | Large Data Management | 16 | 18.0 | 24.9 | 42.9 | 18.1 | 17.8 | 35.9 | 19.9 | 13.4 | 33.3 |
| 13 | Medium Search | 50 | 2.4 | 2.2 | 4.6 | 2.4 | 1.4 | 3.9 | 3.0 | 1.2 | 4.2 |
| 14 | Medium Data Management | 8 | 29.9 | 2.5 | 32.6 | 29.6 | 1.9 | 31.5 | 33.3 | 1.4 | 34.7 |
| 15 | Small Guidance and Control | 3325 | 20.3 | 0.1 | 20.4 | 19.9 | 0.1 | 20.0 | 25.6 | 0.1 | 25.7 |
| | Total Cost | | 161 | 121 | 282 | 160 | 90 | 250 | 204 | 68 | 272 |
| | # System Preferences | | | | 0 | | | 10 | | | 5 |

TABLE 2-12b

Total Life Cycle Cost vs CFA ($ x $10^6$)

1985 Procurement and Software Tool Expenditure of $1M/yr

1976 Average Appl'n SW Cost = $34/Instruction

| SYS # | SYSTEM MISSION | $n_i$ | INTERDATA 8/32 HDW | INTERDATA 8/32 ASW | INTERDATA 8/32 TOTAL | DEC PDP-11 HDW | DEC PDP-11 ASW | DEC PDP-11 TOTAL | IBM S370 HDW | IBM S370 ASW | IBM S370 TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Medium Search | 192 | 3.9 | 5.0 | 8.9 | 4.1 | 3.6 | 7.7 | 4.7 | 2.6 | 7.3 |
| 2 | Medium Command and Control | 27 | 0.7 | 22.2 | 22.9 | 0.7 | 15.8 | 16.5 | 0.9 | 11.8 | 12.7 |
| 3 | Small Search | 100 | 2.2 | 3.0 | 5.2 | 2.1 | 2.2 | 4.3 | 2.6 | 1.6 | 4.2 |
| 4 | Large Command and Control | 178 | 23.0 | 57.8 | 80.8 | 23.0 | 41.2 | 64.2 | 34.5 | 31.0 | 65.5 |
| 5 | Medium Command and Control | 64 | 3.4 | 7.2 | 10.6 | 3.4 | 5.2 | 8.6 | 4.1 | 3.8 | 7.9 |
| 6 | Large Command and Control | 30 | 1.6 | 38.6 | 40.2 | 1.6 | 27.6 | 29.2 | 2.1 | 20.6 | 22.7 |
| 7 | Small Command and Control | 832 | 13.4 | 15.4 | 28.8 | 13.4 | 11.0 | 24.4 | 18.3 | 8.2 | 26.5 |
| 8 | Large Communications | 616 | 36.3 | 27.0 | 63.3 | 35.4 | 19.2 | 54.6 | 47.3 | 14.4 | 61.7 |
| 9 | Small Communications | 800 | 5.5 | 1.2 | 6.7 | 5.3 | 0.8 | 6.1 | 6.4 | 0.6 | 7.0 |
| 10 | Small Communications | 9 | 0.2 | 2.8 | 3.0 | 0.2 | 9.2 | 9.4 | 0.2 | 6.8 | 7.0 |
| 11 | Small Special Purpose | 30 | 0.5 | 2.2 | 2.7 | 0.5 | 1.4 | 1.9 | 0.6 | 1.2 | 1.8 |
| 12 | Large Data Management | 16 | 18.0 | 49.8 | 67.8 | 18.1 | 35.6 | 53.7 | 19.9 | 26.8 | 46.7 |
| 13 | Medium Search | 50 | 2.4 | 4.4 | 6.8 | 2.4 | 2.8 | 5.2 | 3.0 | 2.4 | 5.4 |
| 14 | Medium Data Management | 8 | 29.9 | 5.0 | 34.0 | 29.6 | 3.8 | 33.4 | 33.3 | 2.8 | 36.1 |
| 15 | Small Guidance and Control | 3325 | 20.3 | 0.2 | 20.5 | 19.9 | 0.2 | 20.1 | 25.6 | 0.2 | 25.8 |
| | Total Cost | | 161 | 242 | 403 | 160 | 180 | 340 | 204 | 136 | 340 |
| | # System Preferences | | | | 1 | | | 7 | | | 7 |

## TABLE 2-14

### Summary: Architecture Selection vs Cost Model Parameters

| Case No. | ARCHITECTURE | | | PROCUREMENT YEAR | | ANNUAL SW BASE INVESTMENT | | | AVG. COST PER INSTR. ASW | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | IBM | DEC | INT | 1976 | 1985 | $1M | $2M | $3M | $15 | $30 | Unweighted S, M, R |
| 1 | 3 | 11 | 1 | X | | | | | X | | |
| 2 | 0.5 | 14.5 | 0 | | X | | X | | X | | |
| 3 | 4 | 10.5 | 0.5 | X | | | | | | X | |
| 4 | 0.5 | 14.5 | 0 | | X | | X | | | X | |
| 5 | 5 | 10 | 0 | | X | X | | | X | | |
| 6 | 7 | 7 | 1 | | X | X | | | | X | |
| 7 | 0.3 | 8.3 | 6.3 | | X | | | X | X | | |
| 8 | 0 | 11 | 4 | | X | | X | | X | | X |
| 9 | 2 | 13 | 0 | | X | | X | | | X | X |

## TABLE 2-13

### Total Life Cycle Cost vs CFA

### Unweighted Values of S, M, R

### ($\$ \times 10^6$)

| | | INTERDATA | | DEC | | IBM | |
|---|---|---|---|---|---|---|---|
| | | $17/I | $34/I | $17/I | $34/I | $17/I | $34/I |
| 1985 $2M/YR | TOTAL COST | 251 | 341 | 242 | 310 | 259 | 327 |
| | # SYSTEM PREFERENCES | 4 | 0 | 11 | 13 | 0 | 2 |

perturbations. The results show DEC to be the architecture selected predominantly over the others.

e. SUMMARY/CONCLUSION

(1) Summary

The results of the analysis described herein are summarized in Figure 2-2 for the baseline conditions or parameters, namely, an average applications software cost per instruction of $17 in 1976 and a support software investment rate of $2M annually* for the selected CFA to 1985. Figure 2-2 indicates that:

(a) The average total life cycle cost for all 15 systems is estimated at $1.91B in 1976 and $250M in 1985. The average hardware:software ratio decreases from 12:1 in 1976 to 2.4:1 in 1985.

(b) In 1976, the number of systems selecting the PDP-11 architecture on the basis of life cycle cost is the largest (11). The PDP-11 architecture provides the lowest total life cycle cost (8.0% below the average cost) by a small margin (3.7%) over the 8/32 architecture and by a larger margin (20.0%) over the S/370 architecture.

(c) In 1985, the number of systems selecting the PDP-11 architecture continues to provide the lowest total life cycle cost for all 15 systems by margins of 8.8% and 17.6% over the 8/32 and S/370 architectures.

Other baseline conditions applicable to the results shown in Figure 2-2 are: (1) hardware cost reduction 12:1 from 1976 to 1985; (2) hardware life cycle cost is twice the acquisition cost; and (3) software life cycle cost is 5.5 times the acquisition cost.

The results shown in Figure 2-2 are not significantly changed if the average applications software cost per instruction in 1976 is doubled to $34 (thereby decreasing the hardware:software ratio by a factor of 2) or if the annual support software investment for the selected CFA is increased to $3M or decreased to $1M.

(2) Conclusion

The results obtained with the bottom-up life-cycle cost model show that the DEC PDP-11 architecture would provide the lowest life cycle cost for most of the 15 Army embedded-computer systems considered and for the 15 systems as an entity in 1976 and 1985 under the following conditions:

(a) Applications software cost per instruction of $17 and $34 in 1976. Lower costs are assumed in 1985 as the support software base is augmented.

*Editor's Note: M denotes millions of dollars
B denotes billions of dollars

A. AVERAGE TOTAL LIFE CYCLE COSTS ($000,000)

| Type Cost | 1976 | 1985 |
|---|---|---|
| Hardware | $1750 | $175 |
| Software | 162 | 75 |
| TOTAL | $1912 | $250 |
| HDW/SW Ratios* | 12:1 | 2.4:1 |

B. 1976 ARCHITECTURE COMPARISON

| Architecture | # System Preferences | Relative Total Cost** HDW | SW | Total |
|---|---|---|---|---|
| 8/32 | 1 | .92 | 1.33 | .96 |
| PDP-11 | 11 | .91 | 1.00 | .92 |
| S/370 | 3 | 1.16 | .67 | 1.12 |

C. 1985 ARCHITECTURE COMPARISON

| Architecture | # System Preferences | Relative Total Cost** HDW | SW | Total |
|---|---|---|---|---|
| 8/32 | - | .92 | 1.20 | 1.00 |
| PDP-11 | 14.5 | .91 | .91 | .91 |
| S/370 | 0.5 | 1.16 | .91 | 1.09 |

* Hardware/software ratios are calculated from cost data detailed in Table 2-8
** 1.00 denotes average cost

Figure 2-2. Summary: Bottom Up Life Cycle Cost Analysis

b. Support software investment rate of $1M, $2M and $3M per year to 1985.

c. Architecture test measures of effectiveness (S, M and R) are weighted for each system application.

d. Hardware cost reduction of 10:1 from 1976 to 1985.

e. Hardware life cycle cost is twice acquisition cost, software life cycle cost is 5.5 times acquisition cost.

f. REFERENCES


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a. APPENDIX A - Computation of Processor Speed and Static Storage Ratios

(1) Introduction

This appendix describes the procedure used to compute the processor speed ratio $a_{ij}$ and the static storage ratio $b_{ij}$.

(2) Definition of Terms

The architecture test program has defined three terms ($S_j$, $M_j$, and $R_j$) to measure the effectiveness of architecture j.

$S_j$ is a measure of the amount of memory needed to represent a particular test program on the jth architecture.

$M_j$ is a measure of the processor/memory transfers required to execute a particular test program of the jth architecture, i.e., the number of 8 bit bytes that must be read or written by the processor(s) in primary memory.

$R_j$ is a measure of the internal register-to-register transfers required by the processor to execute a particular test program on the jth architecture.

$a_{ij}$ and $b_{ij}$ are factors which act as penalties or bonuses when applied to the cost model. The degree of penalty or bonus is determined by evaluating the results of running the test programs in terms of S, M, and R and calculating $a_{ij}$ and $b_{ij}$ as shown in this appendix.

(3) Architecture Test Results

Twelve test programs listed in Table 2-A.1, each emphasizing a particular type of processing, were run on the candidate architectures. S, M, and R data were collected by S. Fuller at Carnegie Mellon University. For the purposes of this report the multiple values of S, M, and R were averaged and placed into a 12 by 9 matrix. Each row depicts one of the twelve test routines and the nine columns are comprised of an S, M, and R measure for each of the three architectures.

(4) $a_{ij}/b_{ij}$ Computation

A second matrix, 12 by 15, was developed where again each row depicts one of the twelve test routines and each of the fifteen columns represents a prior generation military computer (PGMC). Each element in the m x n matrix consisted of a weight (Wmn) which was subjectively assigned as a measure of the relevance of test program m to PGMC n. Weight assignment was such that any column (system weight set) summed to unity (Table 2-A.2).

The twelve test routines, listed in Table 2-A.1 were considered to fall into one of two categories:

1. Test programs 1, 2, and 3 relate principally to I/O functions.

2. The remaining programs (4-12) are associated with traditional processor/memory functions.

Within these two subsets, varying degrees of functional overlap occur among the test routines.

Table 2-A.1

Architecture Test Programs

1. I/O Kernel, Four Priority Levels
2. I/O Kernel, FIFO Processing
3. I/O Device Handler
4. Large FFT
5. Character Search
6. Bit Test, Set, or Reset
7. Runge Kutta Integration
8. Linked List Insertion
9. Quick Sort
10. ASC II to Floating Point Conversion Routine
11. Boolean Matrix Transpose
12. Virtual Memory Space Exchange

The first weighting step consisted of assigning gross values to categories 1 and 2 for each system. Subsequently, each initially assigned value was distributed across the test routines within the associated category.

Table 2-A.2

Weights Assigned To Each System To Emphasize or De-Emphasize The Relative Importance Of The Test Program To The System

| SYSTEM | TEST PROGRAM | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | A | B | C | D | E | F | G | H | I | J | K | L |
| 1 | .15 | .05 | .20 | .10 | .15 | .05 | .05 | 0 | .10 | .05 | .05 | .05 |
| 2 | .15 | .05 | .15 | 0 | .20 | .05 | .25 | 0 | .05 | 0 | .05 | .05 |
| 3 | .15 | .05 | .15 | 0 | .35 | .05 | .10 | 0 | .05 | 0 | .05 | .05 |
| 4 | .20 | .05 | .20 | 0 | .20 | .05 | .15 | 0 | .05 | 0 | .05 | .05 |
| 5 | .15 | .10 | .15 | 0 | .30 | .05 | .10 | 0 | .05 | 0 | .05 | .05 |
| 6 | .20 | .05 | .15 | 0 | .25 | .05 | .05 | .05 | .10 | 0 | 0 | .10 |
| 7 | .20 | .05 | .20 | 0 | .15 | .05 | .30 | 0 | .05 | 0 | 0 | 0 |
| 8 | .20 | .05 | .20 | 0 | .25 | .10 | .05 | .10 | .05 | 0 | 0 | 0 |
| 9 | .05 | .15 | .30 | 0 | .35 | .05 | .05 | 0 | .05 | 0 | 0 | 0 |
| 10 | .15 | .05 | .40 | 0 | .25 | .05 | .05 | 0 | .05 | 0 | 0 | 0 |
| 11 | .20 | .10 | .10 | 0 | .35 | .05 | .10 | 0 | .05 | 0 | 0 | .05 |
| 12 | .20 | .05 | .20 | 0 | .20 | 0 | .05 | .10 | .10 | 0 | 0 | .10 |
| 13 | .10 | .05 | .20 | .05 | .30 | .05 | .10 | 0 | .05 | .05 | 0 | .05 |
| 14 | .20 | .05 | .35 | 0 | .20 | .05 | .05 | 0 | .05 | 0 | 0 | .05 |
| 15 | .10 | .10 | .15 | 0 | .05 | .20 | .40 | 0 | 0 | 0 | 0 | 0 |

For example, the Combat Service Support System (CS3) resembles contemporary commercial data processing in its use of COBOL and data bases. Thus, its weighting was positively biased toward I/O and processing routines such as "Linked List Insertion," and negatively biased with regard to mathematical oriented routines such as "Runge Kutta". On the other hand, the Tank Ballistics Application Computer System will be used primarily to perform trajectory computations - its weighting favored "Runge Kutta" but was biased against "Linked List Insertion."

The values of S, M, and R in the 12 x 9 matrix then are normalized by row and multiplied, element by element, by the 12 x 15 matrix of test program weights.

$$S_{3,2} = W_{13}\,S_{12} + W_{23}\,S_{22} + W_{33}\,S_{32} + \text{---} + W_{12,3}\,S_{12,2}$$

Similarly, for system 3, values of S were found for the first and third architectures, i.e., $S_{3,1}$ and $S_{3,3}$. An average S was then calculated for system 3.

$$S_3 = \frac{S_{3,1} + S_{3,2} + S_{3,3}}{3}$$

The value of b for system 3 in architecture 2 was found by solving for:

$$b_{3,2} = \frac{S_{3,2}}{S}$$

In this manner, a value of b for each system in each architecture (15x3) was calculated. These results are shown in Table 2-A.3.

The ratio $a_{ij}$ was determined from the general relationship

$$a = \frac{3 \sum MW + \sum RW}{3\,M + R}$$

The actual procedure of multiplying corresponding elements of the two matrices is identical to that used in the solution of the ratio $b_j$ and will not be repeated here. As in $b_j$, a value of a was calculated for each system in each architecture. The results are shown in Table 2-A.3.

Table 2-A.3

Static Storage Ratio and Processor Speed Ratios for Each Architecture

| SYSTEM MISSION | PROCESSOR SPEED RATIO, $a_{ij}$ | | | STATIC STORAGE RATIO, $b_{ij}$ | | |
|---|---|---|---|---|---|---|
| | INTER-DATA 8/32 | DEC PDP-11 | IBM S370 | INTER-DATA 8/32 | DEC PDP-11 | IBM S370 |
| 1 Medium Search | 0.81 | 0.92 | 1.28 | 0.84 | 0.93 | 1.24 |
| 2 Medium Command and Control | 0.81 | 0.81 | 1.39 | 0.86 | 0.85 | 1.30 |
| 3 Small Search | 0.84 | 0.78 | 1.28 | 0.88 | 0.83 | 1.28 |
| 4 Large Command and Control | 0.79 | 0.78 | 1.44 | 0.81 | 0.81 | 1.38 |
| 5 Medium Command and Control | 0.81 | 0.78 | 1.41 | 0.85 | 0.82 | 1.32 |
| 6 Large Command and Control | 0.79 | 0.83 | 1.38 | 0.84 | 0.84 | 1.32 |
| 7 Small Command and Control | 0.77 | 0.77 | 1.47 | 0.81 | 0.82 | 1.37 |
| 8 Large Communications | 0.81 | 0.75 | 1.46 | 0.84 | 0.80 | 1.37 |
| 9 Small Communications | 0.89 | 0.83 | 1.29 | 0.95 | 0.80 | 1.19 |
| 10 Small Communications | 0.87 | 0.79 | 1.35 | 0.90 | 0.82 | 1.29 |
| 11 Small Special Purpose | 0.78 | 0.73 | 1.49 | 0.83 | 0.78 | 1.39 |
| 12 Large Data Management | 0.80 | 0.85 | 1.36 | 0.83 | 0.85 | 1.32 |
| 13 Medium Search | 0.89 | 0.83 | 1.28 | 0.92 | 0.88 | 1.21 |
| 14 Medium Data Management | 0.83 | 0.77 | 1.41 | 0.84 | 0.79 | 1.37 |
| 15 Small Guidance and Control | 0.80 | 0.76 | 1.42 | 0.86 | 0.82 | 1.32 |

## 3. THE TOP-DOWN MODEL

### a. INTRODUCTION

This paper describes the mathematical formulation, parameter sensitivity, and error analysis of a life-cycle cost model for comparing computer architectures. The model quantitatively compares computer architectures by projecting trends and combining estimates of architecture-dependent hardware and software costs to obtain discounted life-cycle costs and cost ratios.

The model was developed in order to help the Army and Navy determine the most cost effective of three candidate computer architectures, with the intent that this architecture would be the basis of a software compatible family of military computers over the 1978-1990 time period [EsteR76]. The three candidate architectures were the IBM S/370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32. In addition to describing the model, this paper gives the input data and the results of comparing these architectures.

By selectively perturbing the expected values of key parameters and observing the effects, we were able to determine the sensitivity of the model to uncertainties in the input data and to determine the relative importance of each piece of input data. In comparing the IBM S/370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32 computer architectures over the 1978-1990 time frame, the model indicated that the relative cost effectiveness of these architectures was most sensitive to the software-to-hardware ratio of the computing environment and to the support-software base available for each architecture.

The major findings were that for support-software base of about 2 million dollars per year, the IBM S/370 architecture was the most cost effective for software-to-hardware (S/H) greater than about one, while for S/H ratios less than about one fourth the Interdata 8/32 was superior. For intermediate values of S/H the DEC PDP-11 was superior. These findings must, however, be viewed in light of the fact that error analysis shows the uncertainty on the cost ratios to be large compared to the cost ratio differences among the architectures.

Before describing the model, it may be helpful to clarify what we mean by "computer architecture." Although many, often conflicting, definitions of this term appear in the literature, the joint Army/Navy Computer Family Architecture (CFA) Selection Committee [SmitW75, ColeA76, SaliA76] has defined it to be the abstract view of a computer as seen by an assembly language programmer. This view includes the instruction and register sets, interrupt structure, and memory addressing scheme; it excludes hardware attributes, such as cycle time, microprogrammed vs hardwired logic implementations, instruction look-ahead schemes, memory interleaving and cache memories, that are normally transparent to the assembly language programmer. A more precise statement of the Selection Committee's definition appears in Volume 1 of this set of reports.

The Garbage-In-Garbage-Out (GIGO) principle applies to cost models. Cost models often require as input estimates of, among other things: initial investments, service lives, salvage values, operating costs, and the cost of money. Given that most of these involve a forecast of the future, their preparation is a difficult task. Although we can be guided by our own past experiences, the experiences of others, the opinions of qualified personnel, and the results of pilot studies, a degree of uncertainty is always present. This uncertainty does not, however, mean that it is fruitless to adhere to quantitative analytical

techniques because the alternative leads to decisions based solely on judgment and intuition and having a probability of error higher than that of the quantitative approach. A quantitative approach compels the involved individuals to state their estimates explicitly and, unlike the qualitative approach, assures that these data can be subjected to critique and analyzed in a rational manner.

The decision making process usually involves the following four steps:

Step 1) Define the Alternatives
Step 2) Describe the Alternatives
Step 3) Evaluate the Alternatives
Step 4) Consider the Irreducibles

For the CFA project, the first step, define the alternatives, had already been carried out by the Selection Committee before work on the cost model desribed below began. The identified alternatives were to standardize on either:

1) the IBM S/370 architecture,
2) the Digital Equipment Corporation (DEC) PDP-11 architecture, or
3) the Interdata 8/32 architecture

Restricting the life-cycle cost comparisons to these architectural alternatives simplifies the cost model because parameters that might normally be included in the model can be ignored if they are invariant over the architectural alternatives.

The second and third steps (describe and evaluate the alternatives) fall within the domain of the cost model.

The fourth step, consider the irreducibles, can be an important part of the decision process. By irreducibles we mean attributes of the alternatives that have not been, or cannot be, quantitatively described by the model. An example of an irreducible is the willingness of each manufacturer to assist in verifying and establishing his architecture if it is selected. The final decision on the most desirable alternative should consider irreducibles in inverse proportion to the size of the model-generated cost differences between the alternatives. The smaller the differences, the more consideration should be given to irreducibles. Volume eight, final selection, discusses the irreducibles relevant to the CFA project.

b. THE BASIC MODEL

The principal output of the model is a two-dimensional matrix, $R^*$, whose elements, $R^*_{jk}$, $j=1, \ldots N_y$, $k=1, \ldots N_a$, give the discounted cumulative cost of architecture k relative to a reference architecture for a period of j years. Here $N_y$ denotes the maximum time period in years and $N_a$ the number of architectures under examination. An element $R^*_{jk}$ is called a discounted cumulative cost ratio. If the model yields $R^*_{m1} < R^*_{m2}$ then, neglecting irreducibles, architecture 1 is more desirable than architecture 2 for the period j=1 through j=m, since it has a lower cumulative cost for that period.

The study described herein examines cumulative costs over periods of one to thirteen years ($N_y$=13) beginning in 1978. Cumulative costs were calculated only

up to 1990, j=13, because of the increasing difficulty of estimating meaningful values of input parameters with time. Since this study compares only three architectures, we have $N_a=3$. The index k=1 represents the IBM S/370 computer family architecture (the reference architecture), k=2 the Digital Equipment Corporation PDP-11 architecture, and k=3 the Interdata 8/32 architecture.

The model obtains the yearly architecture-dependent cost ($C_{jk}$) by summing the architecture-dependent hardware costs ($H_{jk}$) and software costs ($S_{jk}$),

$$C_{jk} = S_{jk} + H_{jk}. \tag{3.1}$$

The nondiscounted cumulative cost through year m for architecture k, $D_{mk}$, is simply the sum of all costs from year 1 through year m,

$$D_{mk} = \sum_{j=1}^{m} C_{jk} \tag{3.2}$$

The discounted cumulative cost, $D^*_{mk}$, on the other hand, takes into account the time value of money. Since, ignoring inflation, a dollar today is worth more than a dollar tomorrow, the model multiplies cash flows occurring in a year j by a discount factor, $d_j$, and sums the products,

$$D^*_{mk} = \sum_{j=1}^{m} C_{jk} d_j. \tag{3.3}$$

Each discount factor is an average over the year j of the single-payment present-worth factor $w^{-t}$, where

$$w = 1 + q/100 \tag{3.4}$$

and q is the annual discount rate in percent. More specifically, $d_j$ is given by

$$d_j = \int_{j-1}^{j} w^{-t} dt / \int_{j-1}^{j} dt \tag{3.5}$$

$$= (w^{1-j} - w^{-j})/\ln(w)$$

These discount factors are the same as those recommended in [AFR--69] and used in [SADPR74, Volume V].

Since our immediate interest is only in the relative merits of the three architectures, their cumulative cost ratios provide an adequate and useful measure. In addition, the cost ratios are more useful than absolute costs because they serve to cancel out common and possibly unknown multiplicative factors.

Taking architecture one (the IBM S/370) as the reference architecture, we define the nondiscounted cumulative cost ratio as

$$R_{jk} = D_{jk}/D_{j1}, \tag{3.6}$$

and, analogously, the discounted cumulative cost ratio as

$$R^*_{jk} = D^*_{jk}/D^*_{j1}. \tag{3.7}$$

Consequently, we have $R^*_{j1} = R_{j1} = 1$ for $j=1,\ldots N_y$.

(1) Architecture-Dependent Hardware Costs

The model obtains the architecture-dependent hardware costs ($H_{jk}$) by summing the architecture-dependent processor ($P'_{jk}$), main-memory ($M'_{jk}$), and secondary-memory ($E'_{jk}$) expenditures,

$$H_{jk} = P'_{jk} + M'_{jk} + E'_{jk}. \tag{3.8}$$

The following sections describe the method of arriving at values for these expenditures.

(a) System Development Cycle and Yearly Hardware Expenditure

Total yearly hardware expenditures, $B_j$, $j=1 \ldots N_y$, for CFA-related military computer systems are key inputs to the model. They include computer, main-memory, secondary-memory, I/O and peripheral devices, and related expenditures.

Estimating realistic values for $B_j$, $j=1, \ldots N_y$ is a problem since both the number of dollars that will be spent on future DoD military computer systems and the fraction of these dollars that will fall under the jurisdiction of the CFA project are unknown at this time. Fortunately, however, the relative merits of the competing architectures as measured by the model are insensitive to multiplying all the yearly hardware expenditures, $B_j$, $j=1, \ldots N_y$ by the same constant because, neglecting the relatively small yearly support-software expenditures, the constant divides out of the model's equations when we compute the total cumulative-cost ratios. The relative amount spent for hardware in a given year as compared with other years is a more important figure.

Military systems typically require years between initiation of development and full deployment. This phasing-in period is estimated to be approximately equal to average system development cycle time, which experience indicates runs between 3 and 10 years [KossA75], [ChapG73], [PremA76], [BoehB73b, p. 15]. In order to approximate the expenditure levels during this phasing-in period, we assumed that the expenditures $B_j$, $j=1, \ldots N_y$, began at some predetermined level,

$B_1$, increased linearly with time over an initial development period ($B_j$, j=1, ...$N_d$), and then remained constant for the remaining period ($B_j$, j=$N_d$+1, ..$N_y$). For the purpose of the study, the development period, $N_d$, was estimated to be seven years. The sensitivity studies (Cases 31 and 32) also considered the effects of choosing development periods of five and ten years, assuming the same initial and final hardware expenditure levels. The simplifying assumption of constant base hardware expenditures after an initial development period appears to be reasonable because: (1) total ADP expenditures in DoD, when measured in uninflated dollars, have been nearly constant in recent years; (2) the principle of level funding has tended to guide DoD budget allocations; (3) decreasing hardware costs on a per-unit basis have tended to offset increasing hardware requirements; and (4) the exact dollar assumption used is less important than its equal-handed application to each of the candidate architectures.

Although they are few and far between, there are some estimates and projections of computer system budgets available today [FishD74, BoehB72, SADPR74, WithF75]. For our purposes, one of the more useful was D. A. Fisher's study of ADP costs in DoD [FishD74]. In this report, Fisher estimated that in FY 1973, DoD spent 6.2 to 8.3 billion dollars on ADP. He found that approximately one third of this amount originated in each service, and that about 16% of the total went to computer hardware, 45% went to software, and 38% to other ADP costs, such as support and supplies, keypunching, and computer operation. Using these figures, we deduce that 1.0 to 1.3 billion dollars went to computer hardware and roughly 2.8 to 3.7 billion dollars went to software. During a private conversation with the author in May, 1976 [FishD76], D. Fisher mentioned that his recent studies showed that if one were to divide DoD software costs by application, the major portion (approximately 56%) goes for embedded computer systems, i.e., the types of systems the CFA project is designed to influence. Approximately 19% goes for administrative data processing applications wherein COBOL is the principal language, and 5% goes to scientific applications using most commonly FORTRAN. The other 20% goes for other types of applications and indirect costs. Assuming these percentages also applied in FY 1973, this would mean that of the approximately 2.8 to 3.7 billion that went to software, about 1.6 to 2.1 billion went for software for embedded computer systems. If we make the assumption that the software-to-hardware cost ratio for embedded computer systems is approximately the same as that for overall DoD ADP systems, we obtain 0.6 to 0.7 billion dollars for hardware for embedded computer systems. Dividing this by three to obtain an estimate of cost for each service, we obtain 0.2 to 0.23 billion. Of course, not all embedded computer systems will be impacted by CFA. Making the very rough assumption that one fourth would be, we obtain a yearly annual hardware expenditure rate for a single service of about 50 million dollars. For the purpose of our study, we took this figure as our nominal hardware expenditure level.* We also assumed, based on the seven year phase-in period described earlier, that the initial hardware expenditure was about one-seventh of this, or 7 million dollars. In summary, for most of the cases reported in this study, we assumed the yearly base hardware expenditures will remain constant at fifty-million dollars after linearly increasing over a seven-year development period from approximately seven million dollars.

*As pointed out earlier, the overall expenditure level assumed is immaterial since it is the comparative (not absolute) costs that are being computed.

(3) Nominal Yearly Processor Expenditures

The model assumes that the nominal yearly processor expenditures ($K_j$) are constant (u) times the yearly base hardware expenditures ($B_j$),

$$K_j = uB_j. \tag{3.9}$$

Nominal processor expenditures ($K_j$) comprise the nominal CPU ($P_j$) and nominal main memory ($M_j$) expenditures but exclude expenditures for I/O busses, devices, and other peripheral gear whose costs are insensitive to the architecture of the processor,

$$K_j = P_j + M_j. \tag{3.10}$$

We assumed in most cases that the constant u was 0.5; that is, we took the total yearly CPU and main memory costs to be one-half the overall CFA base hardware expenditures. This assumption roughly agrees with a recent survey of DP budgets [McLaR76]. In order to measure the sensitivity of the model to u, we also used values of 0.4 and 0.6 as explained in Section 3.

(b) Yearly Main Memory Expenditures

The model assumes the nominal yearly main memory cost ($M_j$) is a fraction ($\alpha$) of the nominal yearly processor expenditures ($K_j$),

$$M_j = \alpha K_j. \tag{3.11}$$

Based on data on military computer systems found in [KossA75], and [SDC-76a] it appears that $\alpha$ usually lies between 0.5 and 0.8. The value used in most of our calculations was 0.65.

Although nominal main-memory cost is not architecture dependent, actual main-memory cost ($M'_{jk}$) is. We express this dependency as follows:

$$M'_{jk} = p_k s_k a M_j. \tag{3.12}$$

The two coefficients, $p_k$ and $s_k$, are included in this equation because the cost of memory depends upon the efficiency with which an architecture stores programs as well as the rate at which it uses memory in executing them. The parameter $s_k$, the normalized s-measure, is indicative of the memory space required to represent a program when using architecture k. This space includes all the storage required to represent and execute the program exclusive of input/output used by the program (since the same data arrays are used by all candidate architectures). Professor S. Fuller and other members of the computer science department of Carnegie-Mellon University, with the assistance of Army and Navy R/D organizations, obtained the s-measures and also the m- and r-measures reported below by programming a set of test (benchmark) programs on existing machines of the candidate architectures and then normalizing the results [FullS76]. The quantity $p_k$ in equation (3.12) is a cost-to-performance coefficient for architecture k which the model obtains by combining the normalized m and r-measures as follows:

$$p_k = (Vr_k + Wm_k)^{1/g} \tag{3.13}$$

The m-measure, $m_k$, is a measure of the traffic between main memory and the central processor that is required to execute a program when using architecture k. The r-measure, $r_k$, is a measure of the data traffic internal to the central processor. The exponent g follows from a general relationship, probably first examined by Grosch [GrosH53], between performance and cost, i.e., performance = K x cost$^g$. Rein Turn [TurnR74] gives a value of g between 2 and 3; the SADPR-85 Study Group [SADPR74], using more recent data, argues for a lower value of about 1.5. Although this latter value was used in most of our calculations, we also investigated the effects of using values of 1 and 2 (Section 3). The parameters V and W are weighting factors for the r- and m-measures. Their sum is assumed to be one. Because the values obtained for the r- and m-measures are almost equal for each of the candidate architectures, making $r_k$ insensitive to the values of V and W, we took both V and W to be 0.5.

The constant a appears in equation (3.12) because parts of the main memory are insensitive to computer architecture - in particular, the portion occupied by data arrays. The architecture sensitive fraction, a, is called the main-memory static-storage ratio. Most of the calculations assume a equals 0.8. The sensitivity studies, however, also examine the effects of using values of 0.7 and 0.9.

(c) Yearly Central Processor Expenditures

The nominal yearly and architecture-independent central processor expenditures ($P_j$) follow from combining equations (3.10) and (3.11),

$$P_j = (1-\alpha)K_j. \tag{3.14}$$

The actual architecture-dependent central-processor expenditures ($P'_{jk}$) are given by:

$$P'_{jk} = P_k P_j \tag{3.15}$$

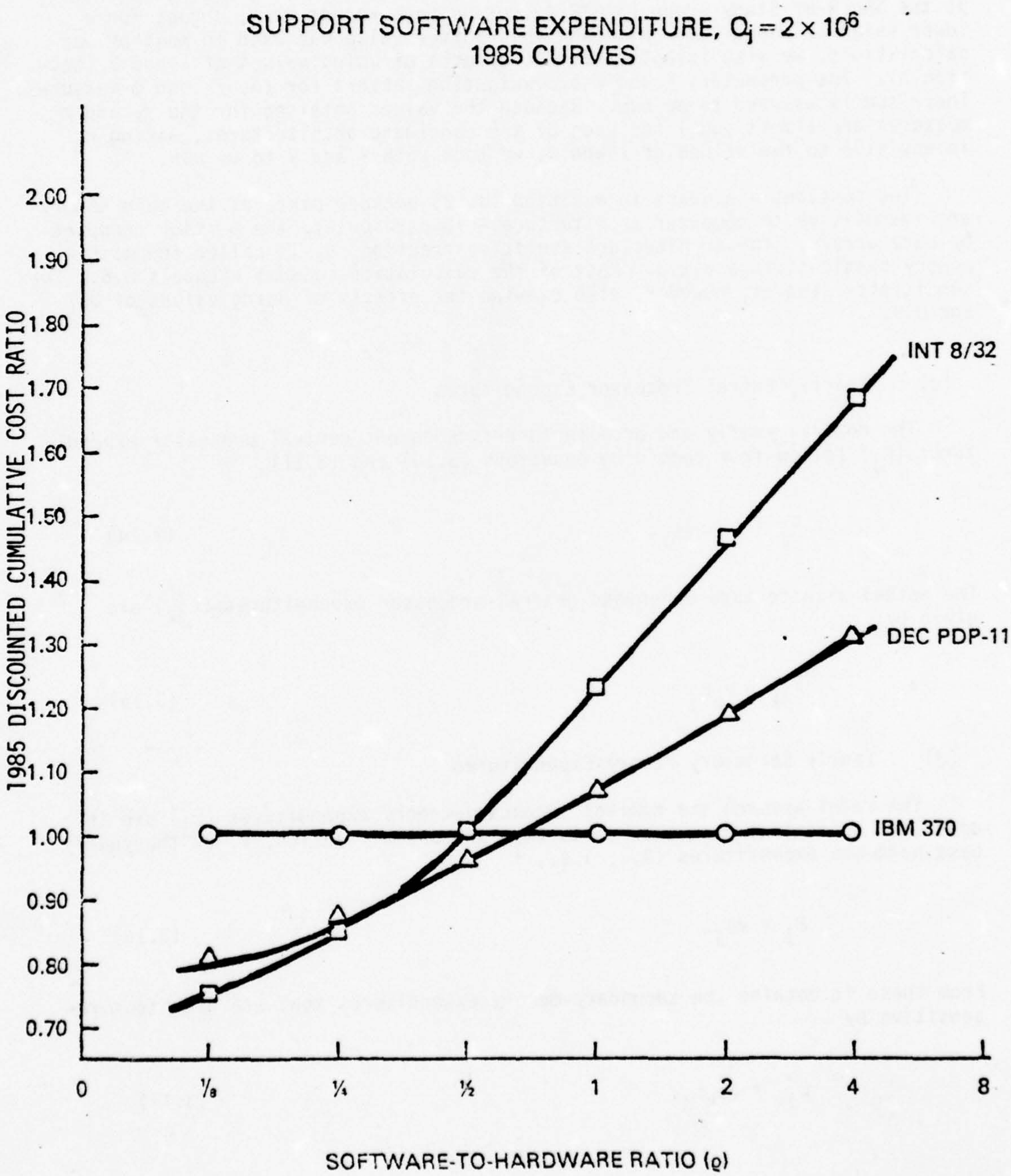
(d) Yearly Secondary Memory Expenditures

The model assumes the nominal secondary-memory expenditures ($E_j$) are independent of nominal processor costs ($K_j$) and are a fraction, v, of the yearly base hardware expenditures ($B_j$), i.e.,

$$E_j = vB_j. \tag{3.16}$$

From these it obtains the secondary-memory expenditures that are architecture-sensitive by

$$E'_{jk} = bs_k E_j. \tag{3.17}$$



SUPPORT SOFTWARE EXPENDITURE, $Q_j = 2 \times 10^6$
1985 CURVES
1985 DISCOUNTED CUMULATIVE COST RATIO
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
INT 8/32
DEC PDP-11
IBM 370
0
1/8
1/4
1/2
1
2
4
8
SOFTWARE-TO-HARDWARE RATIO (ρ)


Figure 3-1

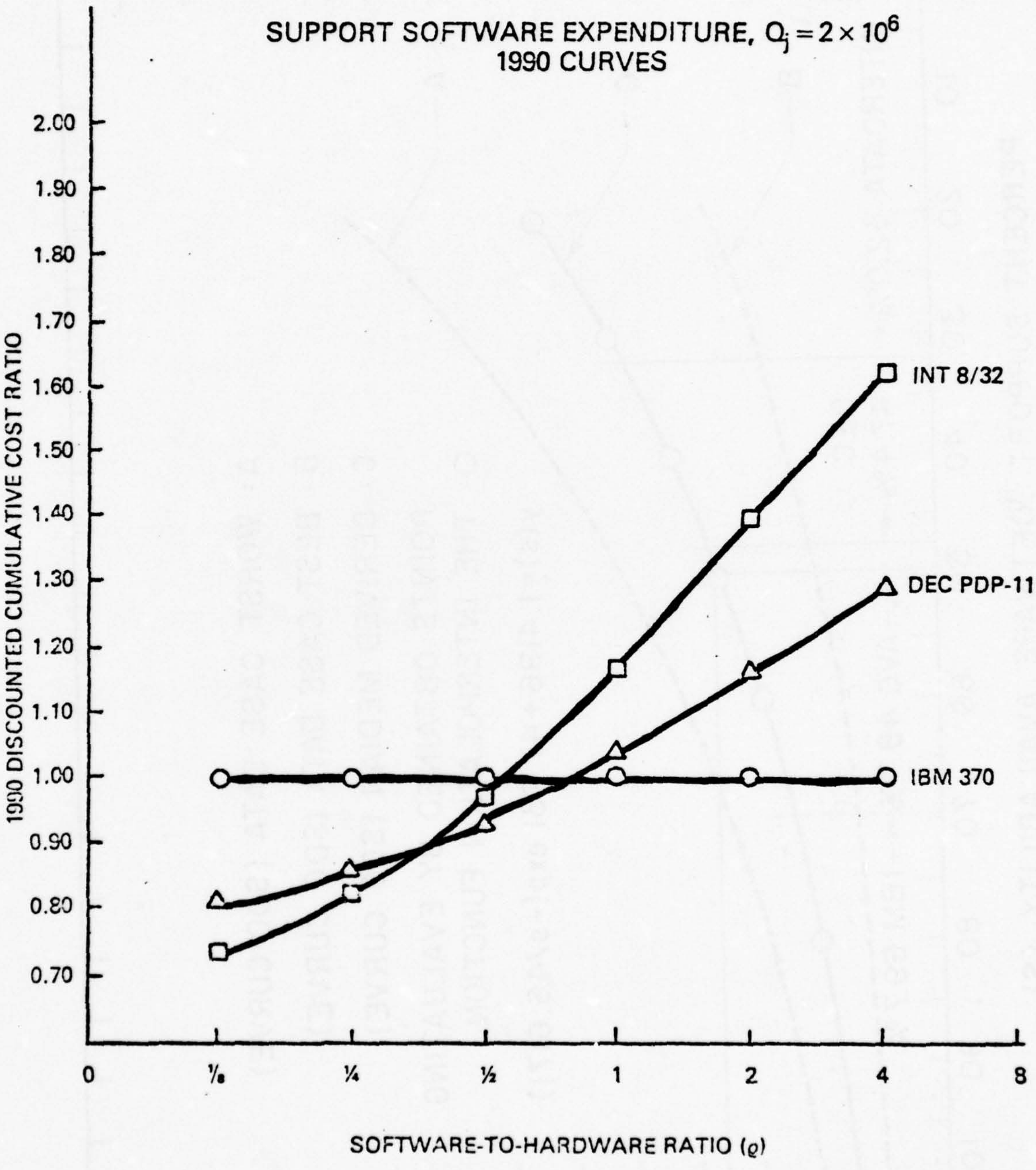

SUPPORT SOFTWARE EXPENDITURE, $Q_j = 2 \times 10^6$
1990 CURVES
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
1990 DISCOUNTED CUMULATIVE COST RATIO
INT 8/32
DEC PDP-11
IBM 370
0
1/8
1/4
1/2
1
2
4
8
SOFTWARE-TO-HARDWARE RATIO ($\varrho$)

Figure 3-2

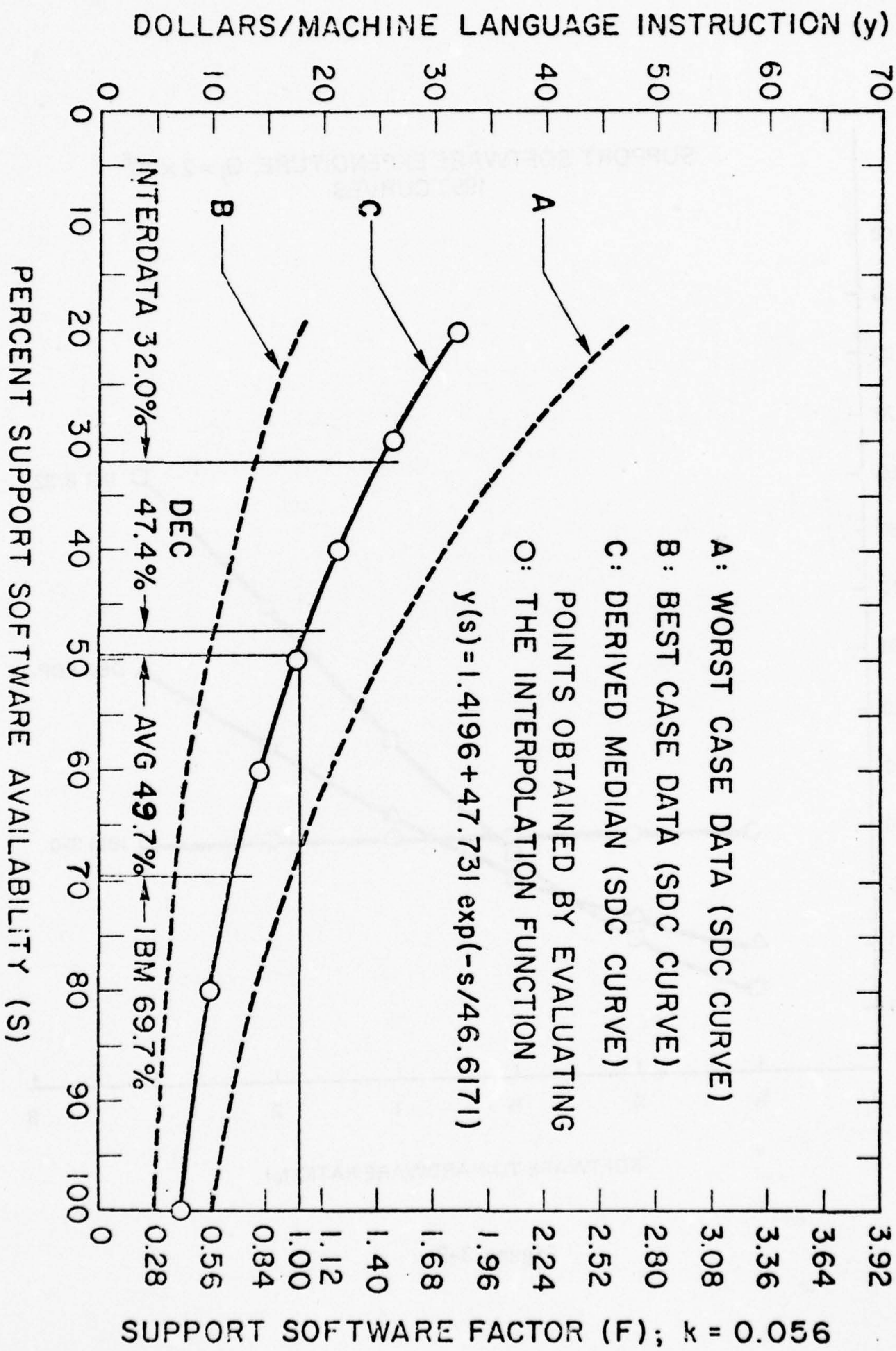

DOLLARS/MACHINE LANGUAGE INSTRUCTION (y)
PERCENT SUPPORT SOFTWARE AVAILABILITY (S)
SUPPORT SOFTWARE FACTOR (F); k = 0.056
A: WORST CASE DATA (SDC CURVE)
B: BEST CASE DATA (SDC CURVE)
C: DERIVED MEDIAN (SDC CURVE)
O: THE INTERPOLATION FUNCTION POINTS OBTAINED BY EVALUATING
y(s)=1.4196+47.731 exp(-s/46.6171)
A
B
C
INTERDATA 32.0%
DEC 47.4%
AVG 49.7%
IBM 69.7%
0
10
20
30
40
50
60
70
80
90
100
0.28
0.56
0.84
1.00
1.12
1.40
1.68
1.96
2.24
2.52
2.80
3.08
3.36
3.64
3.92



Figure 3-3

The constant b, the secondary-memory static-storage ratio, is analogous to the main-memory static-storage ratio (a), and the parameter, $s_k$, is the normalized s-measure discussed in Section 3.2.1.3.

Although it is difficult to determine the value of v that is appropriate to military computer systems, its value is not critical for two reasons: (1) v is small (less than 0.2) for most military computer systems and (2) the fraction of v that is architecture related, i.e., the secondary-memory static-storage ratio (b), is also small (less than 0.2) [SDC-75], [KossA75]. Most of the calculations of this study take v to be 0.1 and b to be 0.2. The sensitivity studies discussed in Section 3 examine the effects of choosing v equal 0.0 and 0.2 and b equal 0.1 and 0.3, and confirm the relative insensitivity of the model to uncertainties in the values of these parameters.

(2) Architecture-Dependent Software Costs

For architecture k, the total yearly software expenditure ($S_{jk}$) of eq. 3.1 is the sum of the yearly support-software expenditure ($Q_j$) plus the architecture-dependent application-software expenditure ($A_jF_{jk}$),

$$S_{jk} = Q_j + A_jF_{jk} \qquad (3.18)$$

(a) Yearly Support Software Expenditures

We define support software to be software tools such as compilers, loaders, linkers, simulators, assemblers, sub-monitors, operating systems, and debug packages and we assume that the amount of money allocated for the development of these tools is independent of the architecture chosen. Hence, the model assumes that support software will be developed with an expenditure of $Q_j$ dollars for each year j where j=1, ...13. For the cases considered in this paper, we let value $Q_j$ be constant at x million dollars, for j=2 through 13 and $Q_1$=0. The sensitivity studies examined the effects of allowing x to range from zero to eight million dollars in two million dollar increments. Although x is architecture independent, it plays a dominant role in determining the lowest cumulative cost alternative. Unless an extremely small CFA program is envisioned, e.g., 5 million dollars per year or less, the support-software costs will be small compared with applications-software costs, and probably will be around 2 million dollars per year.

(b) Architecture-Dependent Applications-Software Costs

The model assumes that base (or nominal) applications-software expenditure in year j, denoted $A_j$, is a constant ($\rho$) times the yearly base hardware expenditure, $B_j$,

$$A_j = \rho B_j \qquad (3.19)$$

For lack of a better name, we call $\rho$ the software-to-hardware ratio. Working with the reports of Fisher [FishD74], and others [WithR75], [TurnR74], [BoehB72], [McLaR76], [SADPR74], we estimate $\rho$ to be about 2.5 to 3 for general-purpose DoD computer systems, and possibly 1/2 to 2 for embedded (tactical) systems [ChapG73], which usually have multiple deployments of the same software and hardware and do not have software bundled into the system price.

The constant $\rho$ is one of the most crucial parameters in the model. Because of its importance and because of the difficulty of estimating its value, we determined the cumulative-cost ratios for 1985 and 1990 using values of $\rho$ of 1/8, 1/4, 1/2, 1, 2, and 4. Figures 3-1 and 3-2 show the results of these calculations for support-software expenditures ($Q_j$) of two million dollars and clearly illustrate the importance of $\rho$ in determining the most cost-effective computer family architecture.

At this point, a word of warning appears to be necessary. The sensitivity studies, to be described in Section 3.3, show that the expected uncertainties of the values of the input parameters can result in substantial uncertainties in the cumulative cost ratios. They imply that the reader should interpret the PDP-11 and Interdata 8/32 curves of Figures 3-1 and 3-2 as ribbons having widths on the order of twenty to thirty percent of the illustrated values; the choice of the most desirable architecture for values of $\rho$ between 1/4 and 2 (the values expected in the military computing environment) is by no means clear. As a consequence, the final decision should examine irreducibles.

The architecture-dependent applications-software costs, mentioned earlier, are $A_jF_{jk}$. Here $F_{jk}$ is the amount of base (nominal) applications-software expenditure that should be used in determining the actual applications-software cost for architecture k. It is dependent upon the available support software for architecture k in year j.

In order to derive an expression for $F_{jk}$ we began with the curves shown in Figure 3-3. These curves give the cost per machine language instruction as a function of available support software. One-hundred percent support software means that an "ideal" set of software tools for military computer systems is available. W. Svirsky, T. Giles, and A. Irwin of System Development Corporation, West Long Beach, New Jersey, generated these curves on the basis of the results of a questionnaire sent to SDC project managers of five large scale (24K to 500K instructions) command and control software efforts [SDC76b], [SvirW76]. The program managers responded to the questionnaire by providing: the cost of software production, the number of instructions generated, the expected percentage increase in project cost that would result if each of thirteen software tools available to them had not been used, and the expected percentage decrease in project cost that would result if an ideal software tool were available. Taking the median of the best and worst case data curves, Svirsky, Irwin and Giles also derived curve C. They noted, however, that the curves are largely judgmental and examples can be found that yield costs per instruction above and below the worst and best case data. Confirming their reservations, we note that the values of cost per instruction shown in Figure 3-3 are lower than those reported by Wolverton [WolvR74] and others [BrooF75], [TabaM74], [PremA76]. Although he does not cite any figures, Manley has found, and gives reasons why, in general the cost per instruction for embedded computer systems is significantly higher than that for normal data processing systems [ManlJ74]. At a September, 1973 symposium, B. Boehm mentioned that Air Force avionics software costs something like $75 per instruction to develop, and that maintenance of the software has run up to $4000 per instruction [BoehB73]. The absolute cost per instruction does not affect the Top Down model, however, because the model depends only upon the relative cost-per-instruction vs support software, as opposed to the absolute cost given by the curve.

From a graph of the SDC median curve, it appeared to us that the interpolation function

$$y(s') = y_m + (y_M - y_m)\exp(-s'/c) \tag{3.20}$$

might provide a reasonably good fit. Here $y$ is the dollars per machine language instruction, $s'$ is the support software availability in percent, and $y_m$, $y_M$, and $c$ are constants. Insisting that this function pass through the three points $(s', y) = (20, 32.5)$, $(50, 17.75)$, and $(80, 10)$, in accordance with the SDC supplied curve, we obtained $y_m$=1.4196, $y_M$=49.151 and c=46.6171. Next we assumed that

$$F_{jk} = k'y(s'), \tag{3.21}$$

where $k'$ is a constant whose value is determined by the additional assumption that when the average of the available support software of the three alternative architectures in year 1, call it $s'$, is substituted in equation (3.21) for $s'$ we should obtain $F_{jk} = 1$. Here we assume $s'$ can be expressed as

$$s' = \frac{100}{3}\left(\frac{U_{11}}{T_1} + \frac{U_{12}}{T_2} + \frac{U_{13}}{T_3}\right), \tag{3.22}$$

where $U_{jk}$ denotes the available support software (measured in dollars) in year j for architecture k, and $T_k$ the dollar value of a 100% support-software base (or ideal support-software base) for architecture k.

Several members of the CFA selection committee surveyed the industry and estimated values for the currently existing support-software base for each candidate architecture and also estimated $T_k$. The values they came up with were:*

| | k | Currently Available Support Software Base ($) | $T_k$ ($) |
|---|---|---|---|
| IBM 370 | 1 | 31.049M | 44.604M |
| DEC PDP-11 | 2 | 20.790M | 43.893M |
| INT 8/32 | 3 | 14.100M | 44.040M |

Making the assumption that the currently available support-software base values given above could be used in the model for $U_{1k}$, k=1, ..3, we obtained from equation (3.22) that $s'$ = 49.7, and

$$\begin{aligned} k' &= 1/y(s') \\ &= 0.05601 \end{aligned} \tag{3.23}$$

*M denotes millions. See Appendix B, Section 3.7 for corrections to these figures.

Figure 3-3 shows the results. Expressing $F_{jk}$ as

$$F_{jk}=f_m+(f_M-f_m)\exp(-hU_{jk}/T_k), \tag{3.24}$$

we have

$$f_m=k'y_m=0.0795 \tag{3.25}$$

$$f_M=k'y_M=2.7528 \tag{3.26}$$

and

$$h=\frac{100}{c}=2.1451. \tag{3.27}$$

The dollar value of the available support software in year j for architecture k, $U_{jk}$, is given by

$$U_{jk}=U_{1k}+\sum_{m=2}^{j}Q_m, \tag{3.28}$$

where $Q_m$ is dollar expenditure for support software in year m.

The values of $Q_m$ have a significant impact on the results of the model. Demonstrating this impact, Figures 3-4 and 3-5 show discounted total cumulative cost ratios for 1985 and 1990. The cases shown assume that $Q_m = x$ for m=2, ...13 and that x ranges from 0 to 8 million dollars in 2 million dollar increments, and that ρ varies by doubling from 1/8 to 4. Figures 3-1 and 3-2 are, of course, subsets of these results. These figures show that by increasing support-software expenditures we can effectively counter high values of ρ that may be characteristic of certain computing environments. They also show that as support-software expenditures increase, the differences between the three candidate architectures decrease. For low values of ρ the Interdata 8/32 appears most desirable, for high values of ρ the IBM S/370 appears to be the best choice; for intermediate values of ρ (between 1/4 and 1) the DEC PDP-11 may be best. As mentioned earlier, because of the uncertainties of the input parameters, these results should be interpreted with discretion.

The trend from case 4 to case 5 (shown in figure 3-4) may at first appear a little perplexing. It indicates that if we increase the expenditure rate for support software development, the PDP-11 and Interdata 8/32 get worse relative to the IBM S/370. One might guess that they would get better. The reason they don't improve is because a point of diminishing returns has been reached. In case 5 we are spending 8 million dollars per year on support software, when the maximum base applications software expenditure is only 6.25 million. Hence, the amount spent on support software is more significant than the amount of reduction it causes in applications software expenditures. Since the cumulative hardware costs for the Interdata and DEC are lower than the hardware costs of the IBM S/370, increasing the support software expenditure in this manner only makes them appear worse, rather than better.

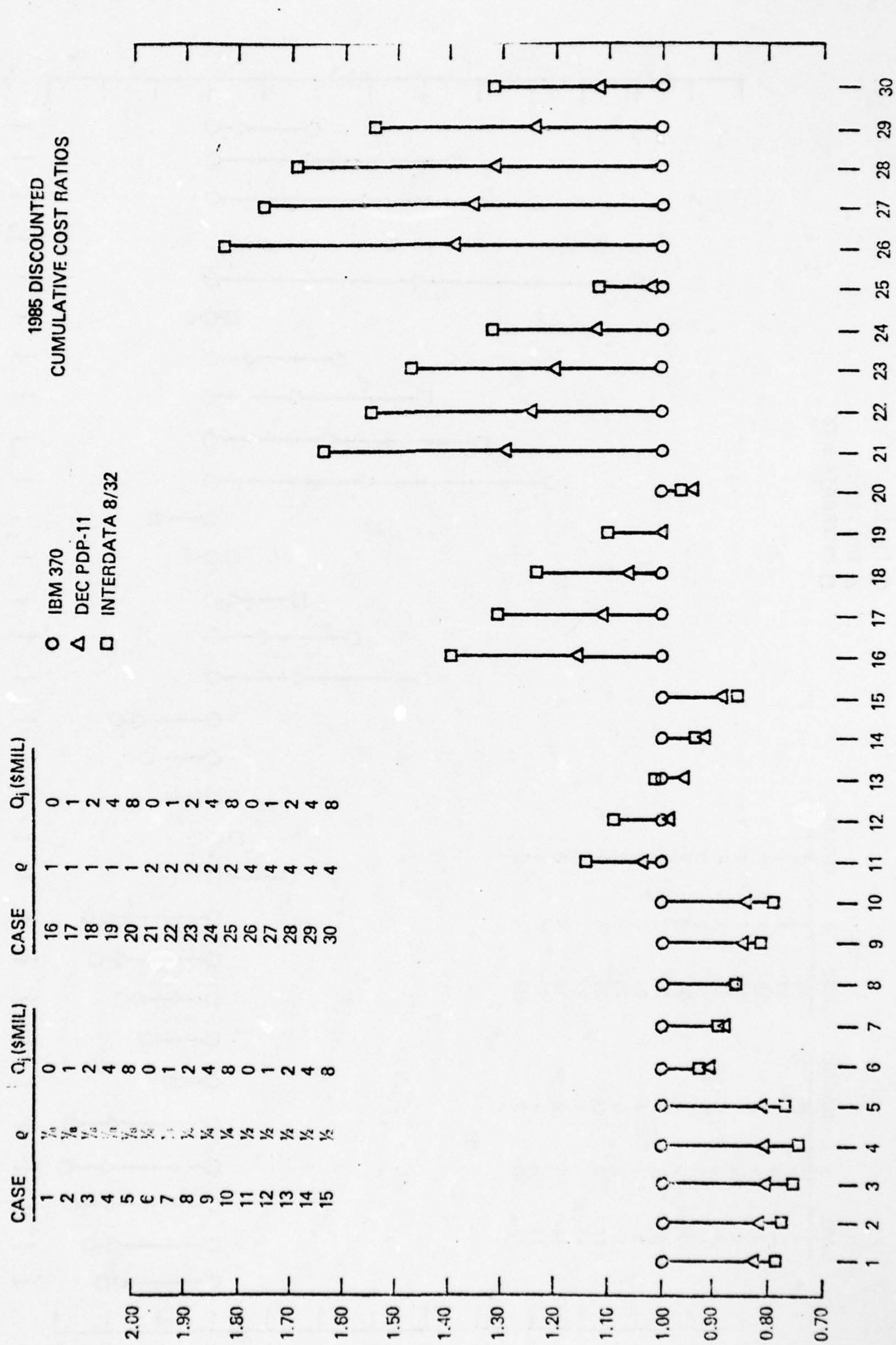

1985 DISCOUNTED
CUMULATIVE COST RATIOS
IBM 370
DEC PDP-11
INTERDATA 8/32
CASE
e
Qi ($MIL)
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70

Figure 3-4

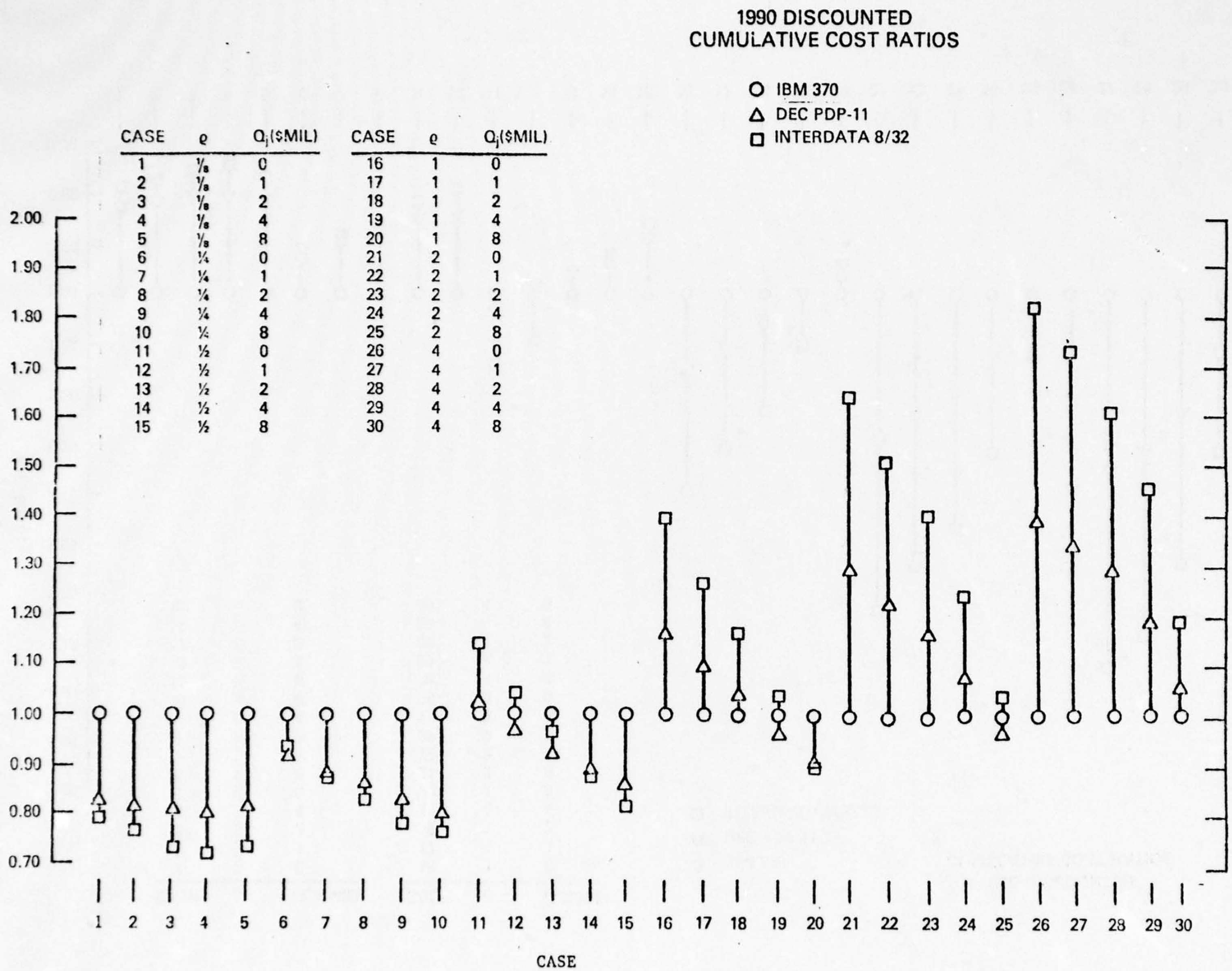

1990 DISCOUNTED
CUMULATIVE COST RATIOS
O IBM 370
Δ DEC PDP-11
□ INTERDATA 8/32
CASE ϱ Qj($MIL) CASE ϱ Qj($MIL)
1 1/8 0 16 1 0
2 1/8 1 17 1 1
3 1/8 2 18 1 2
4 1/8 4 19 1 4
5 1/8 8 20 1 8
6 1/4 0 21 2 0
7 1/4 1 22 2 1
8 1/4 2 23 2 2
9 1/4 4 24 2 4
10 1/4 8 25 2 8
11 1/2 0 26 4 0
12 1/2 1 27 4 1
13 1/2 2 28 4 2
14 1/2 4 29 4 4
15 1/2 8 30 4 8
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
CASE

Figure 3-5

(3) Architecture-Dependent License/Royalty Costs

Architecture license fees or royalties most likely will have to be paid to the selected manufacturer for using his architecture and software. These may be paid in a lump sum in the beginning or as a percentage of each computer as it is manufactured. Since they are expected to be a relatively small fraction of the overall life cycle costs, the model does not account for them.

(4) Summary of Equations

The equation numbers of this section are those used in the previous text.

For $j = 1, \ldots N_y$ and $k = 1, \ldots N_a$

$$A_j = \rho B_j \qquad (3.19)$$

$$K_j = P_j + M_j = uB_j \qquad (3.9 \text{ and } 3.10)$$

$$M_j = \alpha K_j \qquad (3.11)$$

$$P_j = (1-\alpha)K_j \qquad (3.14)$$

$$E_j = vK_j \qquad (3.16)$$

$$U_{jk} = U_{1k} + \sum_{m=2}^{j} Q_m \qquad (3.28)$$

$$C_{jk} = H_{jk} + S_{jk} \qquad (3.1)$$

$$H_{jk} = p_k\,(P_j + s_k a M_j) + s_k b E_j \qquad (3.8),\ (3.15),\ (3.12) \text{ and } (3.17)$$

$$p_k = (Vr_k + Wm_k)^{1/g} \qquad (3.13)$$

$$S_{jk} = Q_j + A_j F_{jk} \qquad (3.18)$$

$$F_{jk} = f_m + (f_M - f_m)\exp(-hU_{jk}/T_k) \qquad (3.24)$$

$$D_{mk} = \sum_{j=1}^{m} C_{jk} \qquad (3.2)$$

| | |
|---|---|
| $p_k$ | cost-to-performance coefficient for architecture k |
| $s_k$ | the normalized s-measure for architecture k |
| $a$ | main-memory static storage ratio |
| $b$ | secondary-memory static storage ratio |
| $r_k$ | normalized r-measure for architecture k |

| | |
|---|---|
| $m_k$ | normalized m-measure for architecture k |
| V | weighting factor for the r-measure |
| W | weighting factor for the m-measure |
| g | exponent of cost in the function relating performance to cost. |
| $Q_j$ | expenditure for support software development in year j. |
| $F_{jk}$ | amount of base (nominal) applications-software expenditure that should be used in determining the actual applications software cost in year j for architecture k. |
| $f_m$ | minimum value $F_{jk}$ can assume |
| $f_M$ | maximum value $F_{jk}$ can assume |
| h | coefficient relating support software availability to rate of decrease of applications software costs |
| $T_k$ | dollar value of an ideal support software base for architecture k |
| $D_{mk}$ | the nondiscounted cumulative cost over the years 1 through m for architecture k |
| $D^*_{mk}$ | the discounted cumulative cost over the years 1 through m for architecture k |
| $d_j$ | the discount factor for year j |
| w | factor derived from the annual discount rate |
| q | annual discount rate in percent |
| $R_{jk}$ | the nondiscounted cumulative cost ratio of architecture k relative to architecture one for a period of j years. |

$$D^*_{mk} = \sum_{j=1}^{m} C_{jk} d_j \qquad (3.3)$$

$$d_j = (w^{1-j} - w^{-j})/\ln(w) \qquad (3.5)$$

$$w = 1 + q/100 \qquad (3.4)$$

$$R_{jk} = D_{jk} / D_{j1} \qquad (3.6)$$

$$R^*_{jk} = D^*_{jk} / D^*_{j1} \qquad (3.7)$$

The parameters appearing in the above equations are briefly:

| | |
|---|---|
| $j$ | index of year (1=1978,.., 13=1990) |
| $k$ | index of architecture (1:S/370, 2:PDP-11, 3:Interdata 8/32) |
| $N_y$ | total number of years considered |
| $N_a$ | total number of architectures |
| $A_j$ | base (nominal) applications software expenditure |
| $B_j$ | base (nominal) hardware expenditure |
| $\rho$ | software-to-hardware ratio |
| $K_j$ | nominal yearly processor cost |
| $P_j$ | nominal yearly central processor expenditure |
| $M_j$ | nominal yearly main memory expenditure |
| $\alpha$ | main-memory to processor ratio |
| $u$ | processor-to-base hardware expenditure ratio |
| $v$ | secondary memory-to-base hardware expenditure ratio |
| $E_j$ | nominal yearly expenditure on secondary memory |
| $U_{jk}$ | dollar value of available support software in year j for architecture k |
| $Q_m$ | dollar expenditure for support software development in year m |
| $C_{jk}$ | yearly architecture-dependent total cost |
| $H_{jk}$ | yearly architecture-dependent total hardware cost |
| $S_{jk}$ | yearly architecture-dependent total software cost |
| $R^*_{jk}$ | the discounted cumulative cost ratio of architecture k relative to architecture one for a period of j years. |

c. SENSITIVITY STUDIES

Figures 3-1, 3-2, 3-4 and 3-5 summarize the results of varying the software-to-hardware ratio ($\rho$ = 1/8, 1/4, 1/2, 1, 2, 4) and the support-software expenditures ($Q_j$ = 0, $1\times10^6$, $2\times10^6$, $4\times10^6$, $8\times10^6$). These variations constitute the first thirty cases of the sensitivity studies.

All of the sensitivity studies assume the discount factor, q, is ten percent (the value recommended by [AFR--69] and used in [SADPR74]).

Further assessing the model's sensitivity, we selectively perturbed individual input parameters about case number 18's ($\rho$=1 and $Q_j=2\times10^6$) input data set to obtain twenty-nine additional input data sets. We chose the case 18 data set as a reference because, at this time, it appears to be the most reasonable of the first thirty data sets based on our current understanding of the characteristics of military embedded computer systems, the candidate architectures, and probable success of CFA. Tables 3-1 and 3-2 summarize the input data sets for cases 31 through 59. In these tables, heavy black lines set off the parameters that we perturbed from the reference values of case 18.

In order to simplify the computations, when perturbing the fraction of available support software in year 1, $U_{1k}/T_k$, we assumed the parameter that the applications software scaling parameter, k', remained constant at the value it had for the case 18 (reference) data set, rather than change it according to equations (3.22) and (3.23).

Sensitivity Studies

| Case | Dev. Cycle | | g | a | b | u | v | $U_{11}/T_1$ | $U_{12}/T_2$ | $U_{13}/T_3$ | p | $Q_j$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 5 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 32 | 10 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 33 | 7 | 0.50 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 34 | 7 | 0.80 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 35 | 7 | 0.65 | 1.0 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 36 | 7 | 0.65 | 2.0 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 37 | 7 | 0.65 | 1.5 | 0.6 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 38 | 7 | 0.65 | 1.5 | 0.9 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 39 | 7 | 0.65 | 1.5 | 0.8 | 0.1 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 40 | 7 | 0.65 | 1.5 | 0.8 | 0.3 | 0.5 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 41 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.4 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 42 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.6 | 0.1 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 43 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.0 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 44 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.2 | 0.697 | 0.474 | 0.320 | 1 | 2 |
| 45 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.600 | 0.474 | 0.320 | 1 | 2 |
| 46 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.800 | 0.474 | 0.320 | 1 | 2 |
| 47 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.400 | 0.320 | 1 | 2 |
| 48 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.600 | 0.320 | 1 | 2 |
| 49 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.200 | 1 | 2 |
| 50 | 7 | 0.65 | 1.5 | 0.8 | 0.2 | 0.5 | 0.1 | 0.697 | 0.474 | 0.400 | 1 | 2 |

Table 3-1

Sensitivity Studies (cont'd)

| Case | | $s'_1$ | $s'_2$ | $s'_3$ | $m'_1$ | $m'_2$ | $m'_3$ | $r'_1$ | $r'_2$ | $r'_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 51 | $s_1$ up 20% | 1.450 | 0.868 | 0.718 | 1.266 | 0.928 | 0.850 | 1.292 | 0.938 | 0.825 |
| 52 | $s_2$ up 20% | 1.089 | 1.200 | 0.746 | 1.266 | 0.928 | 0.850 | 1.292 | 0.938 | 0.825 |
| 53 | $s_3$ up 20% | 1.117 | 0.925 | 0.993 | 1.266 | 0.928 | 0.850 | 1.292 | 0.938 | 0.825 |
| 54 | $m_1$ up 20% | 1.208 | 1.000 | 0.828 | 1.519 | 0.796 | 0.729 | 1.292 | 0.938 | 0.825 |
| 55 | $m_2$ up 20% | 1.208 | 1.000 | 0.828 | 1.155 | 1.114 | 0.775 | 1.292 | 0.938 | 0.825 |
| 56 | $m_3$ up 20% | 1.208 | 1.000 | 0.828 | 1.168 | 0.856 | 1.020 | 1.292 | 0.938 | 0.825 |
| 57 | $r_1$ up 20% | 1.208 | 1.000 | 0.828 | 1.266 | 0.928 | 0.850 | 1.550 | 0.800 | 0.704 |
| 58 | $r_2$ up 20% | 1.208 | 1.000 | 0.828 | 1.266 | 0.928 | 0.850 | 1.178 | 1.126 | 0.752 |
| 59 | $r_3$ up 20% | 1.208 | 1.000 | 0.828 | 1.266 | 0.928 | 0.850 | 1.196 | 0.869 | 0.990 |

Table 3-2

Despite this simplification, we believe the resulting perturbation is useful in assessing the effects of uncertainties in the support software availability. Also, when varying the s-measures in cases 51 through 53, we insisted that the sum of the perturbed s-measures, which we call $s_1'$, $s_2'$, and $s_3'$ in Table 3-2, had to equal the sum of the case 18 s-measures ($s_1$ = 1.208, $s_2$ = 1.000, $s_3$ = 0.828) in order to preserve their relative normalization. In addition, we assumed that, for example in case 51, when the s-measure for architecture 1 moved up by 20%, i.e., $s_1' = 1.2\ s_1$, then $s_2$ and $s_3$ would have to move down by a common factor that would allow the sum to remain invariant. In particular, we insisted that, in this case,

$$s_2' = s_2 t \tag{3.29}$$

and

$$s_3' = s_3 t \tag{3.30}$$

where

$$t = (s_1 + s_2 + s_3 - s_1') \,/\, (s_2 + s_3) \tag{3.31}$$

Table 3-2 also shows the results of perturbing $s_2$, $s_3$, $m_1$, $m_2$, $m_3$, $r_1$, $r_2$, and $r_3$ in an analogous manner.

Figures 3-6 and 3-7 summarize the results of the sensitivity studies (for cases 31 through 59) for 1985 and 1990, respectively. The dotted lines in these figures are indicative of the discounted cumulative cost ratios for the reference data set (case 18), and the arrows show the amount and direction of movement from these values as the result of parameter perturbation. From these figures, we see uncertainties in the percentage of the ideal support-software base available in year 1 ($U_{1k}/T_k$), and uncertainties in u, the ratio of yearly processor expenditure to base hardware expenditure ($K_j/B_j$), can have significant impacts on the results.

Appendix A, Section 3.6, gives some of the input parameters and all of the resulting cumulative costs and cost ratios generated by model for cases 1 through 59.

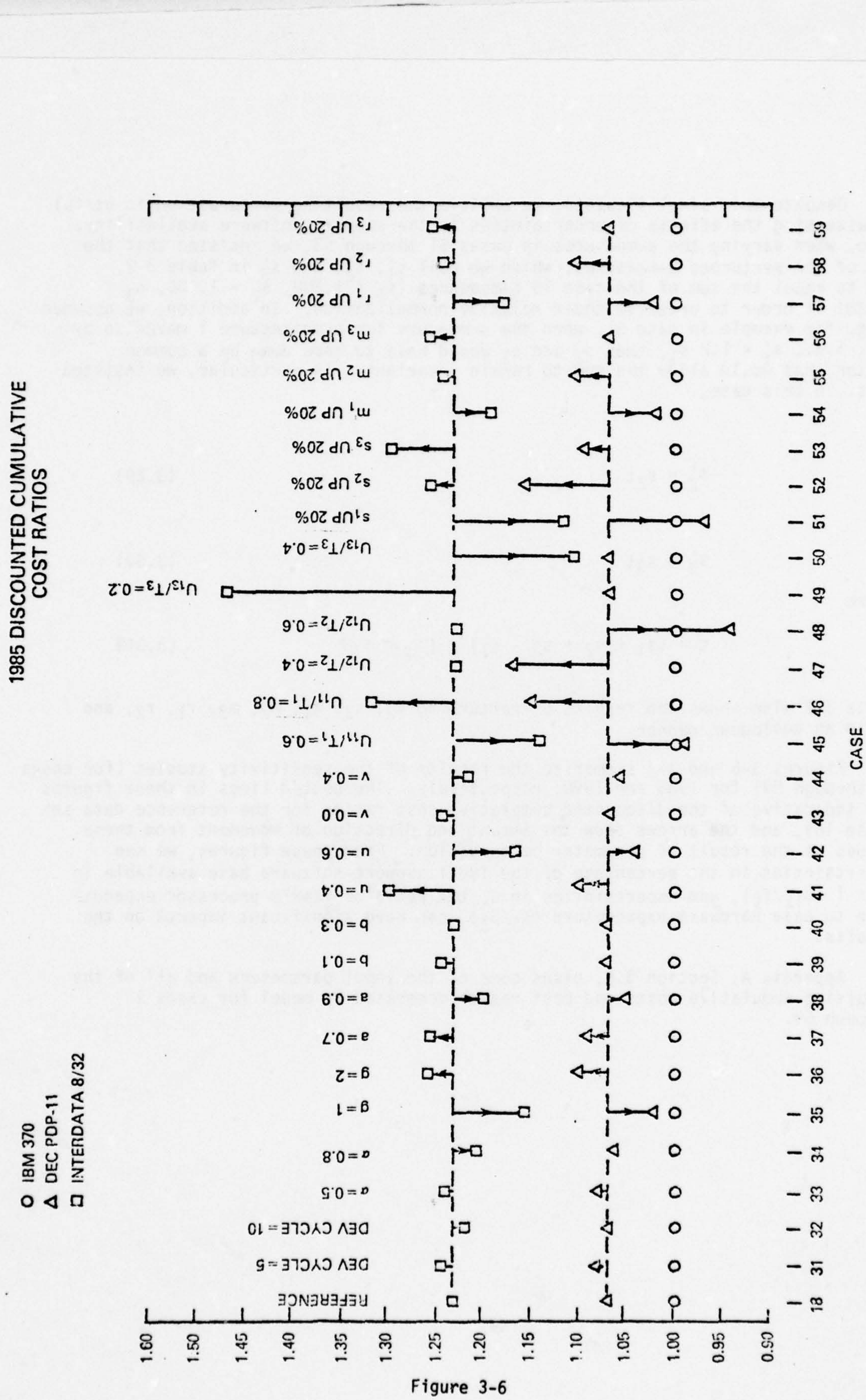

1985 DISCOUNTED CUMULATIVE COST RATIOS
IBM 370
DEC PDP-11
INTERDATA 8/32
CASE
REFERENCE
DEV CYCLE = 5
DEV CYCLE = 10
α = 0.5
α = 0.8
g = 1
g = 2
a = 0.7
a = 0.9
b = 0.1
b = 0.3
u = 0.4
u = 0.6
v = 0.0
v = 0.4
U11/T1 = 0.6
U11/T1 = 0.8
U12/T2 = 0.4
U12/T2 = 0.6
U13/T3 = 0.2
U13/T3 = 0.4
s1 UP 20%
s2 UP 20%
s3 UP 20%
m1 UP 20%
m2 UP 20%
m3 UP 20%
r1 UP 20%
r2 UP 20%
r3 UP 20%
1.60
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
18
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Figure 3-6

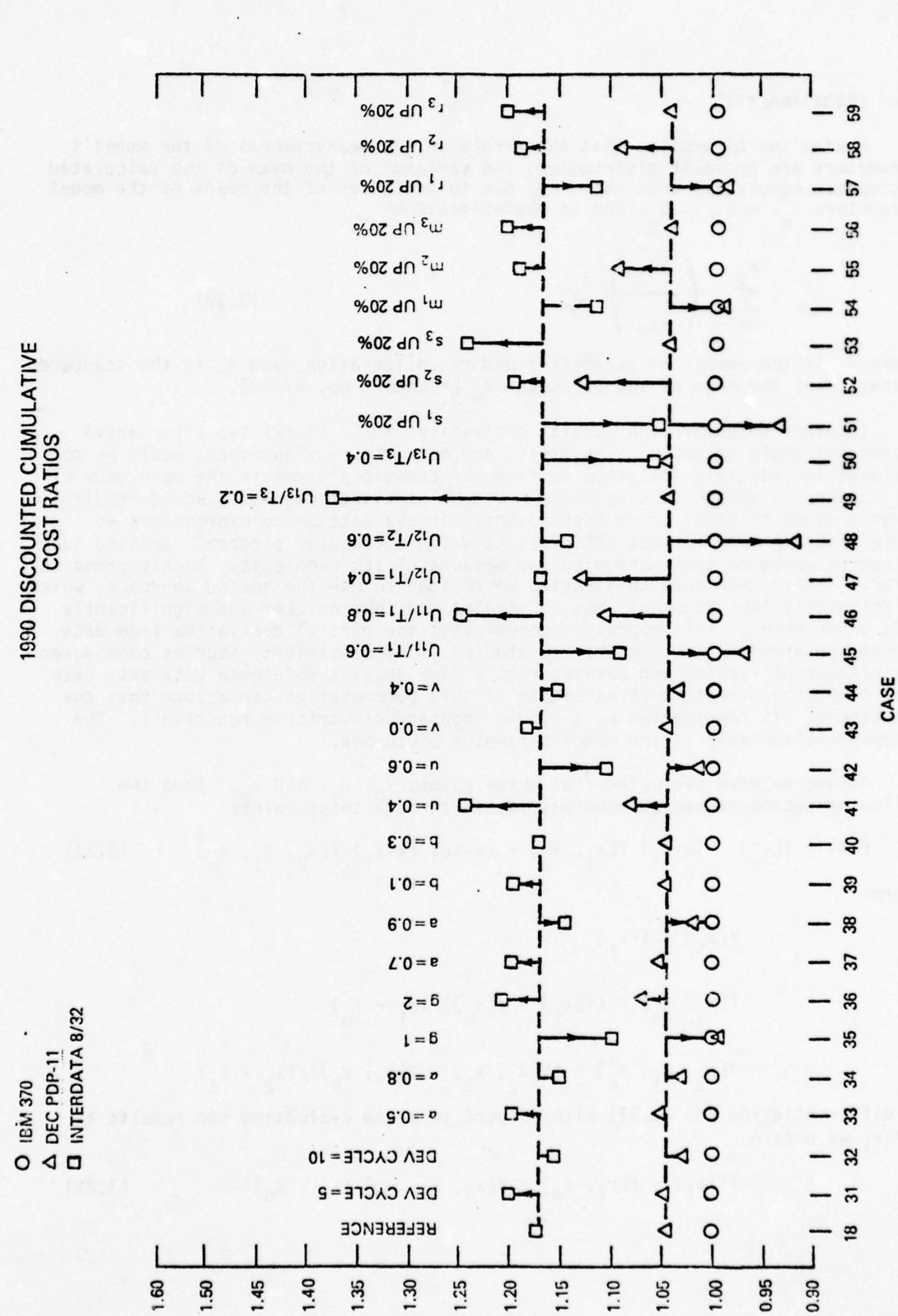
1990 DISCOUNTED CUMULATIVE COST RATIOS
○ IBM 370
△ DEC PDP-11
□ INTERDATA 8/32
1.60
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
REFERENCE
DEV CYCLE = 5
DEV CYCLE = 10
α = 0.5
α = 0.8
g = 1
g = 2
a = 0.7
a = 0.9
b = 0.1
b = 0.3
u = 0.4
u = 0.6
v = 0.0
v = 0.4
$U_{11}/T_1 = 0.6$
$U_{11}/T_1 = 0.8$
$U_{12}/T_1 = 0.4$
$U_{12}/T_2 = 0.6$
$U_{13}/T_3 = 0.2$
$U_{13}/T_3 = 0.4$
$s_1$ UP 20%
$s_2$ UP 20%
$s_3$ UP 20%
$m_1$ UP 20%
$m_2$ UP 20%
$m_3$ UP 20%
$r_1$ UP 20%
$r_2$ UP 20%
$r_3$ UP 20%
18 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
CASE

Figure 3-7

d. ERROR ANALYSIS

Making the assumption that the errors in the measurements of the model's parameters are normally distributed, the variance of the mean of the calculated discounted cumulative cost ratio $R^*_{jk}$ due to variances of the means of the model parameters $X_m$, m=1, ...$N_p$, can be approximated by

$$\sigma^2_{jk} = \sum_{m=1}^{N_p} \left( \frac{\partial R^*_{jk}}{\partial X_m} \right)^2 \sigma^2_m \qquad (3.32)$$

where $N_p$ is the number of parameters under consideration, and $\sigma_m$ is the standard deviation of the mean of the parameter $X_m$ [YounH62, pp. 97-98].

In order to obtain the partial derivatives in Eq (3.32) two alternative approaches could be taken. The first, and more rigorous approach, would be to evaluate the partials analytically from the equations given in the main body of this paper. Although this approach would be straightforward, it would result in several pages of complicated expressions. To evaluate these expressions we would probably find it most efficient to write a computer program. Writing such a program would be time consuming and because of its complexity, highly prone to error. Rather than take this route, we decided to use the second approach, which is definitely less rigorous, but is simpler and thus quicker and significantly less error prone. This approach approximates the partial derivative from data already obtained by the sensitivity studies. The sensitivity studies considered the effects of varying one parameter at a time about a reference data set, case 18. Along the direction of variation of this parameter we can assume that the function $R^*_{ok}$ is represented by a single independent-variable function f. The independent variable is the model parameter perturbed.

Assume we have evaluated f at three points $x_0$, $x_1$, and $x_2$. Then the following second-degree polynominal passes through these points

$$f(x) = f[x_1] + (x-x_1)\, f[x_1, x_0] + (x-xo)\,(x-x_1)\, f[x_2, x_1, x_0] \qquad (3.33)$$

where

$$f[x_1] = f(x_1)$$

$$f[x_1, x_0] = (f[x_1] - f[x_0])/(x_1 - x_0)$$

$$f[x_2, x_1, x_0] = (f[x_2, x_1] - f[x_1, x_0])/(x_2 - x_0)$$

By differentiating Eq. (3.33) with respect to x and evaluating the results at $x = x_1$ we obtain

$$f'(x_1) = f[x_1, x_0] + f[x_2, x_1, x_0]\,(x_1 - x_0) \qquad (3.34)$$

If $x_2 - x_1 = x_1 - x_0$, i.e. the function of f is sampled at equally spaced points, then Eq. (3.34) reduces to

$$f'(x_1) = (f(x_2) - f(x_0))/(x_2 - x_0) \qquad (3.35)$$
$$= f[x_2, x_0]$$

Assuming the value of $x_1$ was equal to the reference data points value, we use $f'(x_1)$ to approximate the partial of $R^*$ with respect to x, evaluated at the reference data point.

For example, the value of u, the nominal yearly processor expenditure, used in the reference test case (case 18) was 0.5. Cases 41 and 42, however, also considered the effects of using u equal to 0.4 and 0.6. Table 3-3 shows the results for the year 1985.

| | IBM | DEC | INT |
|---|---|---|---|
| u | $R^*_{81}$ | $R^*_{82}$ | $R^*_{83}$ |
| 0.4 | 1.00 | 1.10 | 1.30 |
| 0.5 | 1.00 | 1.07 | 1.23 |
| 0.6 | 1.00 | 1.04 | 1.17 |

Table 3-3

Since u was measured at equally spaced points, Eq (3.35) applies and we can approximate the derivatives of $R^*_{8k}$ at the reference data point (case 18) by

$$\frac{\partial R^*_{81}}{\partial u} \approx \frac{1.00 - 1.00}{0.6 - 0.4} = 0$$

$$\frac{\partial R^*_{82}}{\partial u} \approx \frac{1.04 - 1.10}{0.6 - 0.4} = 0.3$$

$$\frac{\partial R^*_{83}}{\partial u} \approx \frac{1.17 - 1.30}{0.6 - 0.4} = 0.65$$

Since architecture one is the reference architecture the partial derivative of $R^*_{j1}$ with respect to any parameter will always be zero.

Table 3-4 summarizes the parameters varied in the sensitivity studies, their values ($X_m$) in the reference test case (case 18), and the resulting partial derivatives calculated using Eqs. (3.34) and (3.35) for the year 1985. Equation (3.35) was used to estimate all partials except those with respect to $\rho$ and Q, which were obtained using Eq. (3.34). No calculations were made for the parameters $B_1$ through $B_{13}$ because these parameters were not varied in the sensitivity studies. As mentioned earlier, however, these parameters just about completely factor out of the equations for the cumulative cost ratios and thus the effects of their errors are believed to be relatively insignificant.

| m | Corresponding Model Parameter | Value $X_m$ | $\partial R^{*DEC}_{82} / \partial X_m$ | $\partial R^{*INT}_{83} / \partial X_m$ |
|---|---|---|---|---|
| 1 | u | 0.5 | -0.30 | -0.65 |
| 2 | $\alpha$ | 0.65 | -0.07 | -0.10 |
| 3 | v | 0.1 | -0.05 | -0.10 |
| 4 | g | 1.5 | +0.08 | +0.10 |
| 5 | a | 0.8 | -0.20 | -0.30 |
| 6 | b | 0.2 | 0.00 | -0.05 |
| 7 | $s_1$ | 1.208 | -0.42 | -0.41 |
| 8 | $s_2$ | 1.000 | +0.45 | +0.15 |
| 9 | $s_3$ | 0.828 | +0.06 | +0.42 |
| 10 | $m_1$ | 1.266 | -0.20 | -0.20 |
| 11 | $m_2$ | 0.928 | +0.22 | +0.05 |
| 12 | $m_3$ | 0.850 | 0.00 | +0.18 |
| 13 | $r_1$ | 1.292 | -0.19 | -0.19 |
| 14 | $r_2$ | 0.938 | +0.21 | +0.05 |
| 15 | $r_3$ | 0.825 | +0.00 | +0.18 |
| 16 | $U_{11}/T_1$ | 0.697 | +0.80 | +0.90 |
| 17 | $U_{12}/T_2$ | 0.474 | -1.16 | +0.00 |
| 18 | $U_{13}/T_3$ | 0.320 | 0.00 | -1.80 |
| 19 | $\rho$ | 1 | +0.20 | +0.38 |
| 20 | $Q_2$-$Q_{13}$ | $2\times10^6$ | $-.04\times10^{-6}$ | $-.08\times10^{-6}$ |
| 21 | $B_1$ | $7.14\times10^6$ | not calculated | not calculated |
| 22 | $B_2$ | $14.3\times10^6$ | " | " |
| 23 | $B_3$ | $21.4\times10^6$ | " | " |
| 24 | $B_4$ | $28.6\times10^6$ | " | " |
| 25 | $B_5$ | $37.5\times10^6$ | " | " |
| 26 | $B_6$ | $42.5\times10^6$ | " | " |
| 27 | $B_7$ - $B_{13}$ | $50.0\times10^6$ | " | " |

Table 3-4

Digital Equipment Corp. PDP-11

| m | Model Parameter | Estimated Value | Estimated $\sigma_m$ | $\sigma_m^2$ | $\partial^2 R_{82}$ | $\partial^2 R_{82} \sigma_m^2$ |
|---|---|---|---|---|---|---|
| 1 | u | 0.50 | 0.10 | 0.0100 | 0.090 | 0.000900 |
| 2 | $\alpha$ | 0.65 | 0.15 | 0.0225 | 0.0049 | 0.000110 |
| 3 | v | 0.10 | 0.05 | 0.0025 | 0.0025 | 0.000006 |
| 4 | g | 1.50 | 0.50 | 0.2500 | 0.0064 | 0.001600 |
| 5 | a | 0.80 | 0.10 | 0.0100 | 0.0400 | 0.000400 |
| 6 | b | 0.20 | 0.10 | 0.0100 | 0.0000 | 0.000000 |
| 7 | $s_1$ | 1.208 | 0.24 | 0.0576 | 0.1764 | 0.010161 |
| 8 | $s_2$ | 1.000 | 0.20 | 0.0400 | 0.2025 | 0.008100 |
| 9 | $s_3$ | 0.828 | 0.16 | 0.0256 | 0.0036 | 0.000092 |
| 10 | $m_1$ | 1.266 | 0.27 | 0.0729 | 0.0400 | 0.002916 |
| 11 | $m_2$ | 0.928 | 0.20 | 0.0400 | 0.0484 | 0.001936 |
| 12 | $m_3$ | 0.850 | 0.18 | 0.0324 | 0.0000 | 0.000000 |
| 13 | $r_1$ | 1.292 | 0.28 | 0.0784 | 0.0361 | 0.000092 |
| 14 | $r_2$ | 0.938 | 0.20 | 0.0400 | 0.0441 | 0.001764 |
| 15 | $r_3$ | 0.825 | 0.18 | 0.0324 | 0.0000 | 0.000000 |
| 16 | $U_{11}/T_1$ | 0.697 | 0.15 | 0.0225 | 0.6400 | 0.000466 |
| 17 | $U_{12}/T_1$ | 0.474 | 0.10 | 0.0100 | 1.3456 | 0.013456 |
| 18 | $U_{13}/T_3$ | 0.320 | 0.07 | 0.0049 | 0.0000 | 0.000000 |
| 19 | $\rho$ | 1 | 0 | 0 | 0.0400 | 0.000000 |
| 20 | $Q_2$-$Q_{13}$ | $2\times10^6$ | 0 | 0 | $1.6\times10^{-15}$ | 0.000000 |
| 21 | $B_1$ | $7.14\times10^6$ | 0 | 0 | nc | nc |
| 22 | $B_2$ | $14.3\times10^6$ | 0 | 0 | nc | nc |
| 23 | $B_3$ | $21.4\times10^6$ | 0 | 0 | nc | nc |
| 24 | $B_4$ | $28.6\times10^6$ | 0 | 0 | nc | nc |
| 25 | $B_5$ | $37.5\times10^6$ | 0 | 0 | nc | nc |
| 26 | $B_6$ | $42.5\times10^6$ | 0 | 0 | nc | nc |
| 27 | $B_7$ - $B_{13}$ | $50.0\times10^6$ | 0 | 0 | nc | nc |

Total = $\sigma_{82}^2$ = 0.041999

nc - not calculated

$\sigma_{82}$ = 0.205

Table 3-5

INTERDATA 8/32

| m | Model Parameter | Estimated Value | Estimated $\sigma_m$ | $\sigma^2_m$ | $\partial^2 R_{83}$ | $\partial^2 R_{83} \sigma_m$ |
|---|---|---|---|---|---|---|
| 1 | u | 0.50 | 0.10 | 0.0100 | 0.4225 | 0.004225 |
| 2 | $\alpha$ | 0.65 | 0.15 | 0.0225 | 0.0100 | 0.000225 |
| 3 | v | 0.10 | 0.05 | 0.0025 | 0.0100 | 0.000025 |
| 4 | g | 1.50 | 0.50 | 0.2500 | 0.0100 | 0.002500 |
| 5 | a | 0.80 | 0.10 | 0.0100 | 0.0900 | 0.000900 |
| 6 | b | 0.20 | 0.10 | 0.0100 | 0.0025 | 0.000025 |
| 7 | $s_1$ | 1.208 | 0.24 | 0.0576 | 0.1681 | 0.009682 |
| 8 | $s_2$ | 1.000 | 0.20 | 0.0400 | 0.0225 | 0.000900 |
| 9 | $s_3$ | 0.828 | 0.16 | 0.0256 | 0.1764 | 0.004516 |
| 10 | $m_1$ | 1.266 | 0.27 | 0.0729 | 0.0400 | 0.002916 |
| 11 | $m_2$ | 0.928 | 0.20 | 0.0400 | 0.0025 | 0.000100 |
| 12 | $m_3$ | 0.850 | 0.18 | 0.0324 | 0.0324 | 0.001050 |
| 13 | $r_1$ | 1.292 | 0.28 | 0.0784 | 0.0361 | 0.002830 |
| 14 | $r_2$ | 0.938 | 0.20 | 0.0400 | 0.0025 | 0.000100 |
| 15 | $r_3$ | 0.825 | 0.18 | 0.0324 | 0.0324 | 0.001050 |
| 16 | $U_{11}/T_1$ | 0.697 | 0.15 | 0.0225 | 0.8100 | 0.018225 |
| 17 | $U_{12}/T_2$ | 0.474 | 0.10 | 0.0100 | 0.0000 | 0.000000 |
| 18 | $U_{13}/T_3$ | 0.320 | 0.07 | 0.0049 | 3.2400 | 0.015876 |
| 19 | $\rho$ | 1 | 0 | 0 | 0.1444 | 0 |
| 20 | $Q_2$-$Q_{13}$ | $2 \times 10^6$ | 0 | 0 | $6.4 \times 10^{-15}$ | 0 |
| 21 | $B_1$ | $7.14 \times 10^6$ | 0 | 0 | nc | 0 |
| 22 | $B_2$ | $14.3 \times 10^6$ | 0 | 0 | nc | 0 |
| 23 | $B_3$ | $21.4 \times 10^6$ | 0 | 0 | nc | 0 |
| 24 | $B_4$ | $28.6 \times 10^6$ | 0 | 0 | nc | 0 |
| 25 | $B_5$ | $37.5 \times 10^6$ | 0 | 0 | nc | 0 |
| 26 | $B_6$ | $42.5 \times 10^6$ | 0 | 0 | nc | 0 |
| 27 | $B_7$ - $B_{13}$ | $50.0 \times 10^6$ | 0 | 0 | nc | 0 |

Total = $\sigma^2_{83}$ = 0.065145

nc - not calculated

$\sigma_{83}$ = 0.225

Table 3-6

Table 3-5 and 3-6 explicitly show the evaluation of Eq (3.38). They give the estimated value of each model parameter as used in the reference test case (case 18). They also give the estimated standard deviation ( $\sigma_m$) of the mean of each parameter. These standard deviations were obtained by the method of "educated guess." It should be noted that the standard deviations for $\rho$ and $Q_j$ were assumed to be zero. This is not because they are actually zero (in fact, they are quite large) but because we desired to obtain an estimate of the standard deviation of the point ($\rho$ = 1) for Figure 3-1. This figure assumes $Q_j$ and $\rho$ are known exactly. From the partials given in Tables 3-4, 3-5 and 3-6 we see, however, that if the errors in $Q_j$ and $\rho$ were included in the calculations they would significantly increase the resulting value of $\sigma_{jk}$.

The results of these calculations indicate that the uncertainties in the model's major results are quite large. Table 3-7 summarizes the findings for a software-to-hardware ratio of one ($\rho$ = 1) and support-software expenditures of two million dollars per year.

| | $k$ | $R^*_{8k}$ | $\sigma_{8k}$ |
|---|---|---|---|
| IBM | 1 | 1.00 | 0.000 |
| DEC | 2 | 1.06 | 0.205 |
| INT | 3 | 1.22 | 0.255 |

Table 3-7

These results imply that because of uncertainties in our input data we cannot really resolve the question of which architecture is the most cost effective for this software-to-hardware ratio by using the top-down model. As a result, irreducibles probably should play a major role in the final decision.

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f. APPENDIX A - SUPPORTING DATA

This appendix gives, in tabular form, some of the input parameters and all of the resulting 1985 and 1990 cumulative costs and cost ratios generated by the model for Cases 1 through 59. Its contents include:

| Table | | |
|---|---|---|
| 3-A.1 | Cases 1-30 | 1985 and 1990 Cumulative Costs |
| 3-A.2 | Cases 1-30 | 1985 and 1990 Cumulative Cost Ratios |
| 3-A.3 | Case 3 | $\rho=1/8$, Detailed Data and Results |
| 3-A.4 | Case 8 | $\rho=1/4$, Detailed Data and Results |
| 3-A.5 | Case 13 | $\rho=1/2$, Detailed Data and Results |
| 3-A.6 | Case 18 | $\rho=1$, Detailed Data and Results |
| 3-A.7 | Case 23 | $\rho=2$, Detailed Data and Results |
| 3-A.8 | Case 28 | $\rho=4$, Detailed Data and Results |
| 3-A.9 | Cases 31-59 | 1985 and 1990 Cumulative Costs |
| 3-A.10 | Cases 31-59 | 1985 and 1990 Cumulative Cost Ratios |

Table 3-A.2 follows from the data in Table A.1. Figures 3-1, 3-2, 3-4 and 3-5 graphically summarize the information in Table 3-A.2.

Tables 3-A.3 through 3-A.8 show detailed input data and results for Cases 3, 8, 13, 18, 23 and 28. These correspond to $Q_j=2\times10^6$, j=2, ...13, and $\rho=1/8$, 1/4, 1/2, 1, 2 and 4. In these tables, the values in row 1 are $A_j$, j=1, ...13. Row 2 shows $B_j$, j=1, ...13. Rows 2, 3, 4 show the total yearly software costs ($S_{jk}$) given by equation (3-18), where k=1 means IBM, k=2 means DEC, and k=3 means Interdata. Rows 6 through 8 give the yearly hardware costs ($H_{jk}$) of equation (3.8). Rows 9 through 11 give the total nondiscounted cumulative costs, as obtained from equation (3.2). Rows 12 through 14 give the total nondiscounted cumulative cost ratios, $R_{jk}$, of equation (3.6). Rows 15 through 20 give the corresponding discounted costs and ratios of equations (3.3) and (3.7). Row 21 gives the discount factors, $d_j$, obtained by applying equation (3.5) for a discount rate (q) of 10%, the value recommended in [AFR---69].

Tables 3-A.9 and 3-A.10 provide the (nondiscounted and discounted) cumulative costs and cost ratios (for 1985 and 1990, cases 31-59). Figures 3-6 and 3-7 graphically summarize the data in Table 3-A.10.

| Case | $\rho$ | $Q_j, j=2,\ldots 13$ ($Mil) | Ratios of Total Non-Discounted Cumulative Cost, $R_{8k}$ 1985 IBM | DEC | INT | Ratios of Total Discounted Cumulative Cost $R^*_{8k}$ 1985 IBM | DEC | INT | Ratios of Total Non-Discounted Cumulative Cost, $R_{13k}$ 1990 IBM | DEC | INT | Ratios of Total Discounted Cumulative Cost, $R^*_{13k}$ 1990 IBM | DEC | INT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1/8 | 0 | 1.00 | 0.830 | 0.789 | 1.00 | 0.827 | 0.791 | 1.00 | 0.825 | 0.790 | 1.00 | 0.824 | 0.789 |
| 2 | 1/8 | 1 | 1.00 | 0.811 | 0.766 | 1.00 | 0.823 | 0.775 | 1.00 | 0.808 | 0.750 | 1.00 | 0.814 | 0.762 |
| 3 | 1/8 | 2 | 1.00 | 0.810 | 0.754 | 1.00 | 0.811 | 0.756 | 1.00 | 0.796 | 0.728 | 1.00 | 0.801 | 0.739 |
| 4 | 1/8 | 4 | 1.00 | 0.810 | 0.741 | 1.00 | 0.809 | 0.745 | 1.00 | 0.791 | 0.712 | 1.00 | 0.800 | 0.724 |
| 5 | 1/8 | 8 | 1.00 | 0.817 | 0.746 | 1.00 | 0.824 | 0.750 | 1.00 | 0.803 | 0.722 | 1.00 | 0.812 | 0.734 |
| 6 | 1/4 | 0 | 1.00 | 0.902 | 0.933 | 1.00 | 0.908 | 0.933 | 1.00 | 0.904 | 0.935 | 1.00 | 0.906 | 0.932 |
| 7 | 1/4 | 1 | 1.00 | 0.880 | 0.885 | 1.00 | 0.884 | 0.892 | 1.00 | 0.864 | 0.859 | 1.00 | 0.873 | 0.868 |
| 8 | 1/4 | 2 | 1.00 | 0.861 | 0.845 | 1.00 | 0.869 | 0.861 | 1.00 | 0.842 | 0.810 | 1.00 | 0.852 | 0.825 |
| 9 | 1/4 | 4 | 1.00 | 0.840 | 0.805 | 1.00 | 0.850 | 0.819 | 1.00 | 0.818 | 0.760 | 1.00 | 0.830 | 0.778 |
| 10 | 1/4 | 8 | 1.00 | 0.836 | 0.777 | 1.00 | 0.843 | 0.793 | 1.00 | 0.815 | 0.743 | 1.00 | 0.826 | 0.760 |
| 11 | 1/2 | 0 | 1.00 | 1.02 | 1.14 | 1.00 | 1.02 | 1.14 | 1.00 | 1.02 | 1.14 | 1.00 | 1.02 | 1.14 |
| 12 | 1/2 | 1 | 1.00 | 0.982 | 1.07 | 1.00 | 0.986 | 1.08 | 1.00 | 0.959 | 1.03 | 1.00 | 0.968 | 1.04 |
| 13 | 1/2 | 2 | 1.00 | 0.946 | 1.00 | 1.00 | 0.957 | 1.01 | 1.00 | 0.915 | 0.945 | 1.00 | 0.930 | 0.972 |
| 14 | 1/2 | 4 | 1.00 | 0.905 | 0.918 | 1.00 | 0.915 | 0.937 | 1.00 | 0.862 | 0.843 | 1.00 | 0.882 | 0.877 |
| 15 | 1/2 | 8 | 1.00 | 0.867 | 0.837 | 1.00 | 0.880 | 0.853 | 1.00 | 0.837 | 0.782 | 1.00 | 0.853 | 0.809 |
| 16 | 1 | 0 | 1.00 | 1.16 | 1.40 | 1.00 | 1.16 | 1.40 | 1.00 | 1.16 | 1.40 | 1.00 | 1.16 | 1.39 |
| 17 | 1 | 1 | 1.00 | 1.11 | 1.30 | 1.00 | 1.11 | 1.31 | 1.00 | 1.08 | 1.26 | 1.00 | 1.09 | 1.27 |
| 18 | 1 | 2 | 1.00 | 1.06 | 1.22 | 1.00 | 1.07 | 1.23 | 1.00 | 1.02 | 1.14 | 1.00 | 1.04 | 1.17 |
| 19 | 1 | 4 | 1.00 | 0.992 | 1.08 | 1.00 | 1.00 | 1.10 | 1.00 | 0.935 | 0.977 | 1.00 | 0.964 | 1.03 |
| 20 | 1 | 8 | 1.00 | 0.919 | 0.935 | 1.00 | 0.935 | 0.964 | 1.00 | 0.873 | 0.848 | 1.00 | 0.899 | 0.895 |
| 21 | 2 | 0 | 1.00 | 1.29 | 1.64 | 1.00 | 1.29 | 1.64 | 1.00 | 1.29 | 1.64 | 1.00 | 1.29 | 1.64 |
| 22 | 2 | 1 | 1.00 | 1.24 | 1.25 | 1.00 | 1.24 | 1.55 | 1.00 | 1.21 | 1.50 | 1.00 | 1.22 | 1.51 |
| 23 | 2 | 2 | 1.00 | 1.19 | 1.46 | 1.00 | 1.20 | 1.47 | 1.00 | 1.14 | 1.37 | 1.00 | 1.16 | 1.40 |
| 24 | 2 | 4 | 1.00 | 1.10 | 1.29 | 1.00 | 1.12 | 1.32 | 1.00 | 1.04 | 1.16 | 1.00 | 1.07 | 1.22 |
| 25 | 2 | 8 | 1.00 | 0.997 | 1.08 | 1.00 | 1.02 | 1.12 | 1.00 | 0.931 | 0.953 | 1.00 | 0.969 | 1.02 |
| 26 | 4 | 0 | 1.00 | 1.39 | 1.83 | 1.00 | 1.39 | 1.83 | 1.00 | 1.39 | 1.82 | 1.00 | 1.39 | 1.82 |
| 27 | 4 | 1 | 1.00 | 1.35 | 1.75 | 1.00 | 1.35 | 1.75 | 1.00 | 1.33 | 1.70 | 1.00 | 1.34 | 1.72 |
| 28 | 4 | 2 | 1.00 | 1.30 | 1.66 | 1.00 | 1.31 | 1.68 | 1.00 | 1.26 | 1.58 | 1.00 | 1.28 | 1.62 |
| 29 | 4 | 4 | 1.00 | 1.22 | 1.51 | 1.00 | 1.24 | 1.54 | 1.00 | 1.14 | 1.36 | 1.00 | 1.18 | 1.43 |
| 30 | 4 | 8 | 1.00 | 1.09 | 1.26 | 1.00 | 1.12 | 1.31 | 1.00 | 1.01 | 1.08 | 1.00 | 1.06 | 1.18 |

Table 3-A.1

| | | | Total Non-Discounted Cumulative Cost ($Mil), $D_{8k}$ 1985 | | | Total Discounted Cumulative Cost ($Mil), $D^*_{8k}$ 1985 | | | Total Non-Discounted Cumulative Cost ($Mil), $D_{13k}$ 1990 | | | Total Discounted Cumulative Cost ($Mil), $D^*_{13k}$ 1990 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case | $\rho$ | $Q_j$, j=2,...13 ($Mil) | IBM | DEC | INT | IBM | DEC | INT | IBM | DEC | INT | IBM | DEC | INT |
| 1 | 1/8 | 0 | 171 | 142 | 135 | 107 | 88.5 | 84.6 | 343 | 283 | 271 | 171 | 141 | 135 |
| 2 | 1/8 | 1 | 175 | 142 | 134 | 109 | 89.7 | 84.5 | 344 | 278 | 258 | 172 | 140 | 131 |
| 3 | 1/8 | 2 | 179 | 145 | 135 | 113 | 91.6 | 85.4 | 349 | 278 | 254 | 176 | 141 | 130 |
| 4 | 1/8 | 4 | 189 | 153 | 140 | 120 | 97.1 | 89.4 | 364 | 288 | 259 | 185 | 148 | 134 |
| 5 | 1/8 | 8 | 213 | 174 | 159 | 136 | 112 | 102 | 406 | 326 | 293 | 207 | 168 | 152 |
| 6 | 1/4 | 0 | 193 | 174 | 180 | 120 | 109 | 112 | 385 | 348 | 360 | 192 | 174 | 179 |
| 7 | 1/4 | 1 | 192 | 169 | 170 | 121 | 107 | 108 | 376 | 325 | 323 | 189 | 165 | 164 |
| 8 | 1/4 | 2 | 194 | 167 | 164 | 122 | 106 | 105 | 373 | 314 | 302 | 189 | 161 | 156 |
| 9 | 1/4 | 4 | 200 | 168 | 161 | 127 | 108 | 104 | 380 | 311 | 289 | 194 | 161 | 151 |
| 10 | 1/4 | 8 | 220 | 184 | 171 | 140 | 118 | 111 | 416 | 339 | 309 | 213 | 176 | 162 |
| 11 | 1/2 | 0 | 235 | 240 | 269 | 147 | 150 | 168 | 470 | 479 | 538 | 234 | 239 | 268 |
| 12 | 1/2 | 1 | 227 | 223 | 243 | 143 | 141 | 154 | 439 | 421 | 452 | 222 | 215 | 232 |
| 13 | 1/2 | 2 | 223 | 211 | 224 | 141 | 135 | 143 | 422 | 386 | 399 | 215 | 200 | 209 |
| 14 | 1/2 | 4 | 221 | 200 | 203 | 141 | 129 | 132 | 413 | 356 | 348 | 212 | 187 | 186 |
| 15 | 1/2 | 8 | 233 | 202 | 195 | 150 | 132 | 128 | 435 | 364 | 340 | 225 | 192 | 182 |
| 16 | 1 | 0 | 320 | 371 | 447 | 200 | 232 | 280 | 640 | 741 | 894 | 319 | 369 | 445 |
| 17 | 1 | 1 | 298 | 330 | 388 | 188 | 209 | 246 | 566 | 612 | 711 | 288 | 314 | 366 |
| 18 | 1 | 2 | 282 | 300 | 344 | 179 | 192 | 221 | 520 | 531 | 592 | 268 | 278 | 314 |
| 19 | 1 | 4 | 265 | 263 | 287 | 170 | 171 | 188 | 478 | 447 | 467 | 249 | 240 | 256 |
| 20 | 1 | 8 | 261 | 240 | 244 | 169 | 158 | 163 | 474 | 414 | 402 | 248 | 223 | 222 |
| 21 | 2 | 0 | 490 | 632 | 803 | 306 | 396 | 502 | 980 | 1265 | 1606 | 488 | 630 | 800 |
| 22 | 2 | 1 | 439 | 544 | 678 | 278 | 345 | 430 | 820 | 995 | 1227 | 420 | 514 | 636 |
| 23 | 2 | 2 | 400 | 477 | 582 | 256 | 307 | 376 | 716 | 820 | 979 | 374 | 435 | 525 |
| 24 | 2 | 4 | 352 | 389 | 455 | 228 | 256 | 301 | 607 | 629 | 705 | 323 | 346 | 395 |
| 25 | 2 | 8 | 316 | 315 | 340 | 207 | 211 | 232 | 553 | 515 | 527 | 295 | 286 | 301 |
| 26 | 4 | 0 | 830 | 1156 | 1516 | 519 | 723 | 948 | 1661 | 2312 | 3031 | 828 | 1152 | 1510 |
| 27 | 4 | 1 | 720 | 972 | 1258 | 456 | 617 | 800 | 1327 | 1760 | 2261 | 683 | 912 | 1175 |
| 28 | 4 | 2 | 637 | 831 | 1060 | 408 | 536 | 685 | 1108 | 1397 | 1753 | 585 | 749 | 946 |
| 29 | 4 | 4 | 525 | 642 | 791 | 343 | 425 | 527 | 866 | 992 | 1181 | 471 | 557 | 674 |
| 30 | 4 | 8 | 425 | 465 | 534 | 283 | 317 | 370 | 710 | 716 | 776 | 389 | 411 | 460 |

Table 3-A.2

Year Case 3

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 0.893 | 1.78 | 2.68 | 3.57 | 4.46 | 5.36 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 0.607 | 3.12 | 3.54 | 3.89 | 4.18 | 4.42 | 4.61 | 4.41 | 4.24 | 4.08 | 3.93 | 3.80 | 3.68 | 3 |
| (2) DEC | 9.35 | 3.71 | 4.34 | 4.86 | 5.28 | 5.61 | 5.86 | 5.54 | 5.26 | 5.01 | 4.77 | 4.56 | 4.37 | 4 |
| (3) INT | 1.27 | 4.32 | 5.18 | 5.87 | 6.42 | 6.85 | 7.18 | 6.75 | 6.35 | 6.00 | 5.67 | 5.38 | 5.11 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.8 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.87 | 16.6 | 33.0 | 54.0 | 79.6 | 110 | 144 | 179 | 213 | 247 | 281 | 315 | 349 | 9 |
| (2) DEC | 4.03 | 14.0 | 27.6 | 44.9 | 65.8 | 90.0 | 118 | 145 | 172 | 199 | 225 | 252 | 278 | 10 |
| (3) INT | 3.85 | 13.4 | 26.3 | 42.6 | 62.0 | 84.4 | 110 | 135 | 159 | 183 | 207 | 231 | 254 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 0.827 | 0.843 | 0.847 | 0.831 | 0.27 | 0.818 | 0.819 | 0.810 | 0.808 | 0.806 | 0.801 | 0.800 | 0.796 | 13 |
| (3) INT | 0.790 | 0.807 | 0.807 | 0.789 | 0.779 | 0.767 | 0.764 | 0.754 | 0.746 | 0.741 | 0.737 | 0.733 | 0.728 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.67 | 14.8 | 27.7 | 42.8 | 59.5 | 77.3 | 95.8 | 113 | 128 | 142 | 154 | 166 | 176 | 15 |
| (2) DEC | 3.84 | 12.4 | 23.2 | 36.5 | 49.2 | 63.6 | 78.3 | 91.6 | 104 | 114 | 124 | 133 | 141 | 16 |
| (3) INT | 3.67 | 11.9 | 22.1 | 33.8 | 46.4 | 59.7 | 73.2 | 85.4 | 96.3 | 106 | 115 | 123 | 130 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 0.822 | 0.838 | 0.838 | 0.832 | 0.827 | 0.823 | 0.817 | 0.811 | 0.812 | 0.803 | 0.805 | 0.801 | 0.801 | 19 |
| (3) INT | 0.786 | 0.804 | 0.798 | 0.790 | 0.780 | 0.772 | 0.764 | 0.756 | 0.752 | 0.746 | 0.747 | 0.741 | 0.739 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1/8$  $Q_j = 2\times10^6$  Dev. Cycle = 7  $\alpha = 0.65$  $g = 1.5$  $a = 0.8$  $b = 0.2$

$s_1, s_2, s_3$ = 1.208, 1.000, 0.828  $m_1, m_2, m_3$ = 1.266, 0.928, 0.850  $r_1, r_2, r_3$ = 1.292, 0.938 0.825

Table 3-A.3

Year Case 8

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 1.78 | 3.57 | 5.36 | 7.14 | 8.93 | 10.7 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12 5 | 12.5 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 1.22 | 4.23 | 5.08 | 5.78 | 6.36 | 6.83 | 7.21 | 6.82 | 6.47 | 6.16 | 5.86 | 5.60 | 5.36 | 3 |
| (2) DEC | 1.87 | 5.42 | 6.69 | 7.72 | 8.55 | 9.21 | 9.72 | 9.10 | 8.53 | 8.01 | 7.54 | 7.12 | 6.74 | 4 |
| (3) INT | 2.54 | 6.64 | 8.36 | 9.74 | 10.8 | 11.7 | 12.4 | 11.5 | 10.7 | 9.99 | 9.34 | 8.75 | 8.22 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.8 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 5.48 | 18.3 | 36.2 | 59.2 | 87.0 | 120 | 157 | 194 | 230 | 266 | 302 | 338 | 373 | 9 |
| (2) DEC | 4.96 | 16.6 | 32.6 | 52.8 | 76.9 | 105 | 136 | 167 | 197 | 227 | 256 | 285 | 314 | 10 |
| (3) INT | 5.12 | 17.0 | 33.1 | 53.2 | 77.0 | 104 | 135 | 164 | 193 | 222 | 249 | 276 | 302 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 0.905 | 0.907 | 0.900 | 0.892 | 0.884 | 0.875 | 0.866 | 0.861 | 0.856 | 0.853 | 0.848 | 0.843 | 0.842 | 13 |
| (3) INT | 0.934 | 0.929 | 0.914 | 0.899 | 0.885 | 0.867 | 0.860 | 0.845 | 0.839 | 0.834 | 0.824 | 0.816 | 0.810 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 5.23 | 16.3 | 30.5 | 46.9 | 65.0 | 84.3 | 104 | 122 | 138 | 153 | 166 | 178 | 189 | 15 |
| (2) DEC | 4.73 | 14.8 | 27.4 | 41.9 | 57.6 | 74.1 | 90.9 | 106 | 120 | 132 | 143 | 152 | 161 | 16 |
| (3) INT | 4.89 | 15.2 | 27.9 | 42.3 | 57.8 | 74.0 | 90.2 | 105 | 118 | 129 | 139 | 148 | 156 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 0.904 | 0.908 | 0.898 | 0.893 | 0.886 | 0.879 | 0.874 | 0.869 | 0.870 | 0.863 | 0.861 | 0.854 | 0.852 | 19 |
| (3) INT | 0.935 | 0.932 | 0.914 | 0.902 | 0.889 | 0.878 | 0.867 | 0.861 | 0.855 | 0.843 | 0.837 | 0.831 | 0.825 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1/4$ $Q_j = 2x10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938\ 0.825$

Table 3-A.4

Year Case 13

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 3.57 | 7.14 | 10.7 | 14.3 | 17.9 | 21.4 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 2.43 | 6.47 | 8.16 | 9.57 | 10.7 | 11.7 | 12.4 | 11.6 | 10.9 | 10.3 | 9.73 | 9.20 | 8.73 | 3 |
| (2) DEC | 3.74 | 8.84 | 11.4 | 13.4 | 15.1 | 16.4 | 17.4 | 16.2 | 15.1 | 14.0 | 13.1 | 12.2 | 11.5 | 4 |
| (3) INT | 5.09 | 11.3 | 14.7 | 17.5 | 19.7 | 21.4 | 22.7 | 21.0 | 19.4 | 18.0 | 16.7 | 15.5 | 14.4 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.8 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 6.69 | 21.8 | 42.8 | 69.5 | 102 | 139 | 182 | 223 | 264 | 304 | 344 | 383 | 422 | 9 |
| (2) DEC | 6.83 | 21.9 | 42.6 | 68.5 | 99.1 | 134 | 173 | 211 | 248 | 284 | 319 | 353 | 386 | 10 |
| (3) INT | 7.67 | 24.2 | 46.6 | 74.5 | 107 | 144 | 185 | 224 | 262 | 298 | 333 | 366 | 399 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.02 | 1.00 | 0.995 | 0.986 | 0.972 | 0.964 | 0.950 | 0.946 | 0.939 | 0.934 | 0.927 | 0.922 | 0.915 | 13 |
| (3) INT | 1.15 | 1.11 | 1.09 | 1.07 | 1.05 | 1.04 | 1.02 | 1.00 | 0.992 | 0.980 | 0.968 | 0.956 | 0.945 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 6.38 | 19.4 | 36.0 | 55.2 | 76.1 | 98.2 | 121 | 141 | 160 | 176 | 190 | 204 | 215 | 15 |
| (2) DEC | 6.52 | 19.6 | 35.9 | 54.4 | 74.4 | 95.2 | 116 | 135 | 151 | 166 | 178 | 190 | 200 | 16 |
| (3) INT | 7.32 | 21.6 | 39.3 | 59.3 | 80.6 | 102 | 124 | 143 | 160 | 174 | 188 | 199 | 209 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.02 | 1.01 | 0.997 | 0.986 | 0.978 | 0.969 | 0.959 | 0.957 | 0.944 | 0.943 | 0.937 | 0.931 | 0.930 | 19 |
| (3) INT | 1.15 | 1.11 | 1.09 | 1.07 | 1.06 | 1.04 | 1.02 | 1.01 | 1.00 | 0.989 | 0.989 | 0.975 | 0.972 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1/2$ $Q_j = 2\times10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938$ 0.825

Table 3-A.5

Year Case 18 (Reference)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.86 | 10.9 | 14.3 | 17.1 | 19.4 | 21.3 | 22.8 | 21.3 | 19.9 | 18.6 | 17.5 | 16.4 | 15.4 | 3 |
| (2) DEC | 7.48 | 15.7 | 20.8 | 24.9 | 28.2 | 30.8 | 32.9 | 30.4 | 28.1 | 26.0 | 24.2 | 22.5 | 21.0 | 4 |
| (3) INT | 10.2 | 20.6 | 27.4 | 33.0 | 37.4 | 40.8 | 43.5 | 40.0 | 36.8 | 34.0 | 31.4 | 29.0 | 26.9 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.8 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 9.12 | 28.6 | 55.8 | 90.1 | 131 | 178 | 231 | 282 | 332 | 381 | 428 | 475 | 520 | 9 |
| (2) DEC | 10.6 | 32.5 | 62.6 | 99.9 | 144 | 193 | 248 | 300 | 350 | 398 | 444 | 488 | 531 | 10 |
| (3) INT | 12.8 | 38.5 | 73.7 | 117 | 167 | 224 | 285 | 344 | 399 | 451 | 500 | 547 | 592 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.16 | 1.14 | 1.12 | 1.11 | 1.10 | 1.08 | 1.07 | 1.06 | 1.05 | 1.04 | 1.04 | 1.03 | 1.02 | 13 |
| (3) INT | 1.40 | 1.35 | 1.32 | 1.30 | 1.27 | 1.26 | 1.23 | 1.22 | 1.20 | 1.18 | 1.17 | 1.15 | 1.14 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 8.70 | 25.6 | 47.0 | 71.6 | 98.3 | 126 | 154 | 179 | 202 | 221 | 239 | 254 | 268 | 15 |
| (2) DEC | 10.1 | 29.1 | 52.8 | 79.6 | 108 | 137 | 166 | 192 | 214 | 234 | 250 | 265 | 278 | 16 |
| (3) INT | 12.2 | 34.5 | 62.2 | 93.3 | 126 | 160 | 192 | 221 | 245 | 266 | 284 | 300 | 314 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.16 | 1.14 | 1.12 | 1.11 | 1.10 | 1.09 | 1.08 | 1.07 | 1.06 | 1.06 | 1.05 | 1.04 | 1.04 | 19 |
| (3) INT | 1.40 | 1.35 | 1.32 | 1.30 | 1.28 | 1.26 | 1.25 | 1.23 | 1.21 | 1.20 | 1.19 | 1.18 | 1.17 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1$ $Q_j = 2x10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938$ $0.825$

Table 3-A.6

Year Case 23

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 14.3 | 28.6 | 42.9 | 57.1 | 71.4 | 85.7 | 100 | 100 | 100 | 100 | 1.00 | 1.00 | 1.00 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 9.72 | 19.9 | 26.6 | 32.3 | 36.9 | 40.7 | 43.7 | 40.6 | 37.8 | 35.2 | 32.9 | 30.8 | 28.9 | 3 |
| (2) DEC | 15.0 | 29.4 | 39.5 | 47.8 | 54.4 | 59.7 | 63.8 | 58.8 | 54.2 | 50.1 | 46.4 | 43.0 | 39.9 | 4 |
| (3) INT | 20.4 | 39.1 | 52.8 | 64.0 | 72.8 | 79.7 | 84.9 | 78.0 | 71.7 | 65.9 | 60.7 | 56.0 | 51.7 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.8 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 14.0 | 42.4 | 81.9 | 131 | 190 | 256 | 330 | 400 | 468 | 534 | 596 | 657 | 716 | 9 |
| (2) DEC | 18.4 | 53.6 | 102 | 163 | 233 | 311 | 397 | 477 | 553 | 625 | 693 | 785 | 820 | 10 |
| (3) INT | 22.9 | 67.3 | 128 | 202 | 288 | 383 | 486 | 582 | 672 | 756 | 835 | 909 | 979 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.28 | 1.26 | 1.24 | 1.24 | 1.23 | 1.21 | 1.20 | 1.19 | 1.18 | 1.17 | 1.16 | 1.15 | 1.14 | 13 |
| (3) INT | 1.64 | 1.59 | 1.56 | 1.54 | 1.56 | 1.50 | 1.47 | 1.46 | 1.44 | 1.42 | 1.40 | 1.38 | 1.37 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 13.3 | 38.0 | 69.1 | 105 | 143 | 182 | 221 | 256 | 286 | 312 | 336 | 356 | 374 | 15 |
| (2) DEC | 17.2 | 48.1 | 86.5 | 130 | 175 | 222 | 267 | 307 | 340 | 370 | 395 | 416 | 435 | 16 |
| (3) INT | 21.9 | 60.3 | 108 | 161 | 217 | 274 | 329 | 376 | 416 | 450 | 470 | 503 | 525 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.29 | 1.26 | 1.25 | 1.24 | 1.22 | 1.22 | 1.21 | 1.20 | 1.19 | 1.18 | 1.18 | 1.17 | 1.16 | 19 |
| (3) INT | 1.65 | 1.59 | 1.56 | 1.53 | 1.52 | 1.50 | 1.49 | 1.47 | 1.45 | 1.44 | 1.42 | 1.41 | 1.40 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 2$ $Q_j = 2\times10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938$ $0.825$

Table 3-A.7

AD- 487 ARMY ELECTRONICS COMMAND FORT MONMOUTH N J F/G 9/2
COMPUTER FAMILY ARCHITECTURE SELECTION COMMITTEE FINAL REPORT. --ETC(U)
SEP 77 A H COLEMAN, W SVIRSKY, A T IRWIN

UNCLASSIFIED ECOM-4535 NL

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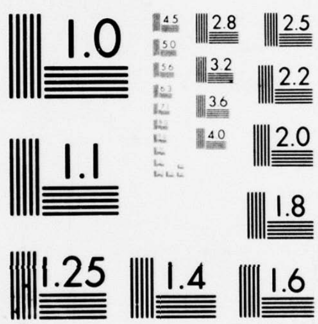


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Year Case 28

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 28.6 | 57.1 | 85.7 | 114 | 143 | 171 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 19.4 | 37.7 | 51.3 | 62.6 | 71.8 | 79.3 | 85.4 | 79.2 | 73.6 | 68.5 | 63.8 | 59.6 | 55.8 | 3 |
| (2) DEC | 29.9 | 56.7 | 77.0 | 93.6 | 107 | 117 | 126 | 116 | 106 | 98.2 | 90.7 | 83.9 | 77.8 | 4 |
| (3) INT | 40.7 | 67.3 | 104 | 125 | 144 | 157 | 168 | 154 | 141 | 130 | 120 | 110 | 102 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 23.7 | 70.0 | 134 | 214 | 307 | 412 | 528 | 637 | 740 | 839 | 933 | 1022 | 1108 | 9 |
| (2) DEC | 33.0 | 95.9 | 182 | 288 | 411 | 546 | 694 | 831 | 960 | 1080 | 1192 | 1298 | 1397 | 10 |
| (3) INT | 43.3 | 125 | 236 | 372 | 529 | 702 | 888 | 1060 | 1219 | 1368 | 1505 | 1633 | 1753 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.39 | 1.37 | 1.36 | 1.34 | 1.34 | 1.32 | 1.31 | 1.30 | 1.30 | 1.29 | 1.28 | 1.27 | 1.26 | 13 |
| (3) INT | 1.83 | 1.78 | 1.76 | 1.74 | 1.72 | 1.70 | 1.68 | 1.66 | 1.65 | 1.63 | 1.61 | 1.60 | 1.58 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 22.6 | 62.8 | 113 | 170 | 231 | 293 | 355 | 408 | 454 | 494 | 529 | 559 | 585 | 15 |
| (2) DEC | 31.5 | 86.0 | 154 | 230 | 310 | 390 | 469 | 536 | 593 | 642 | 684 | 719 | 749 | 16 |
| (3) INT | 41.3 | 112 | 200 | 298 | 400 | 502 | 601 | 685 | 756 | 816 | 867 | 910 | 946 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.39 | 1.37 | 1.36 | 1.35 | 1.34 | 1.33 | 1.32 | 1.31 | 1.31 | 1.30 | 1.29 | 1.29 | 1.28 | 19 |
| (3) INT | 1.83 | 1.78 | 1.77 | 1.75 | 1.73 | 1.71 | 1.69 | 1.68 | 1.66 | 1.65 | 1.64 | 1.63 | 1.62 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 4$ $Q_j = 2\times10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938$ $0.825$

Table 3-A.8

| Case | Comment | Total Non-Discounted Cumulative Cost ($Mil), $D_{8k}$ 1985 IBM | DEC | INT | Total Discounted Cumulative Cost ($Mil), $D^*_{8k}$ 1985 IBM | DEC | INT | Total Non-Discounted Cumulative Cost ($Mil), $D_{13k}$ 1990 IBM | DEC | INT | Total Discounted Cumulative Cost ($Mil), $D^*_{13k}$ 1990 IBM | DEC | INT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | Reference | 282 | 300 | 344 | 179 | 192 | 221 | 520 | 531 | 592 | 268 | 278 | 314 |
| 31 | Dev. Cycle = 5 | 339 | 362 | 416 | 221 | 238 | 274 | 577 | 593 | 665 | 310 | 324 | 368 |
| 32 | Dev. Cycle = 10 | 207 | 219 | 250 | 131 | 140 | 160 | 440 | 445 | 494 | 217 | 224 | 251 |
| 33 | $\alpha$ = 0.5 | 283 | 304 | 349 | 180 | 194 | 224 | 522 | 538 | 604 | 269 | 282 | 320 |
| 34 | $\alpha$ = 0.8 | 282 | 296 | 338 | 179 | 190 | 217 | 519 | 523 | 581 | 267 | 275 | 308 |
| 35 | g = 1 | 294 | 298 | 339 | 187 | 190 | 218 | 545 | 526 | 582 | 280 | 276 | 309 |
| 36 | g = 2 | 276 | 301 | 346 | 176 | 193 | 222 | 509 | 533 | 598 | 262 | 280 | 317 |
| 37 | a = 0.7 | 271 | 292 | 338 | 172 | 187 | 217 | 497 | 515 | 580 | 257 | 270 | 308 |
| 38 | a = 0.9 | 294 | 308 | 350 | 187 | 197 | 225 | 543 | 546 | 604 | 280 | 286 | 320 |
| 39 | b = 0.1 | 279 | 297 | 342 | 178 | 190 | 220 | 514 | 526 | 588 | 265 | 276 | 312 |
| 40 | b = 0.3 | 285 | 302 | 346 | 181 | 194 | 222 | 526 | 536 | 597 | 271 | 281 | 316 |
| 41 | u = 0.4 | 252 | 278 | 326 | 161 | 178 | 210 | 460 | 487 | 556 | 238 | 257 | 296 |
| 42 | u = 0.6 | 312 | 322 | 362 | 198 | 206 | 232 | 580 | 574 | 629 | 298 | 300 | 332 |
| 43 | v = 0.0 | 276 | 295 | 340 | 176 | 189 | 218 | 508 | 521 | 584 | 262 | 273 | 310 |
| 44 | v = 0.4 | 288 | 305 | 348 | 183 | 195 | 223 | 532 | 541 | 601 | 274 | 283 | 318 |
| 45 | U11/T1 = 0.6 | 305 | 300 | 344 | 194 | 192 | 221 | 556 | 531 | 592 | 288 | 278 | 314 |
| 46 | U11/T1 = 0.8 | 263 | 300 | 344 | 167 | 192 | 221 | 489 | 531 | 592 | 251 | 278 | 314 |
| 47 | U12/T2 = 0.4 | 282 | 327 | 344 | 179 | 210 | 221 | 520 | 573 | 592 | 268 | 302 | 314 |
| 48 | U12/T2 = 0.6 | 282 | 263 | 344 | 179 | 168 | 221 | 520 | 471 | 592 | 268 | 246 | 314 |
| 49 | U13/T3 = 0.2 | 282 | 300 | 408 | 179 | 192 | 263 | 520 | 531 | 694 | 268 | 278 | 370 |
| 50 | U13/T3 = 0.4 | 282 | 300 | 309 | 179 | 192 | 198 | 520 | 531 | 538 | 268 | 278 | 284 |
| 51 | s1 up 20% | 302 | 291 | 337 | 192 | 186 | 216 | 560 | 513 | 579 | 288 | 269 | 307 |
| 52 | s2 up 20% | 272 | 313 | 338 | 173 | 200 | 218 | 500 | 557 | 582 | 258 | 292 | 309 |
| 53 | s3 up 20% | 275 | 295 | 354 | 175 | 189 | 227 | 505 | 520 | 613 | 261 | 273 | 324 |
| 54 | m1 up 20% | 292 | 295 | 339 | 185 | 189 | 218 | 539 | 521 | 584 | 277 | 273 | 310 |
| 55 | m2 up 20% | 278 | 307 | 341 | 177 | 196 | 219 | 512 | 544 | 587 | 264 | 285 | 312 |
| 56 | m3 up 20% | 278 | 297 | 349 | 177 | 190 | 224 | 513 | 525 | 604 | 264 | 276 | 320 |
| 57 | r1 up 20% | 292 | 295 | 339 | 185 | 189 | 218 | 539 | 520 | 584 | 278 | 273 | 310 |
| 58 | r2 up 20% | 278 | 307 | 341 | 177 | 196 | 219 | 512 | 544 | 587 | 264 | 285 | 312 |
| 59 | r3 up 20% | 279 | 297 | 349 | 177 | 190 | 224 | 513 | 525 | 604 | 264 | 276 | 320 |

Table 3-A.9

| Case | Comment | Total Non-Discounted Cumulative Cost Ratios 1985, $R_{8k}$ | | | Total Discounted Cumulative Cost Ratios 1985, $R^*_{8k}$ | | | Total Non-Discounted Cumulative Cost Ratios 1990, $R_{13,k}$ | | | Total Discounted Cumulative Cost Ratios 1990, $R^*_{13,k}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IBM | DEC | INT | IBM | DEC | INT | IBM | DEC | INT | IBM | DEC | INT |
| 18 | Reference | 1.00 | 1.06 | 1.22 | 1.00 | 1.07 | 1.23 | 1.00 | 1.02 | 1.14 | 1.00 | 1.04 | 1.17 |
| 31 | Dev. Cycle = 5 | 1.00 | 1.07 | 1.23 | 1.00 | 1.08 | 1.24 | 1.00 | 1.03 | 1.15 | 1.00 | 1.04 | 1.19 |
| 32 | Dev. Cycle = 10 | 1.00 | 1.06 | 1.21 | 1.00 | 1.07 | 1.22 | 1.00 | 1.01 | 1.12 | 1.00 | 1.03 | 1.16 |
| 33 | $\alpha$ = 0.5 | 1.00 | 1.07 | 1.23 | 1.00 | 1.08 | 1.24 | 1.00 | 1.03 | 1.16 | 1.00 | 1.05 | 1.19 |
| 34 | $\alpha$ = 0.8 | 1.00 | 1.05 | 1.20 | 1.00 | 1.06 | 1.21 | 1.00 | 1.01 | 1.12 | 1.00 | 1.03 | 1.15 |
| 35 | g = 1 | 1.00 | 1.01 | 1.15 | 1.00 | 1.02 | 1.16 | 1.00 | 0.965 | 1.07 | 1.00 | 0.986 | 1.10 |
| 36 | g = 2 | 1.00 | 1.09 | 1.25 | 1.00 | 1.10 | 1.26 | 1.00 | 1.05 | 1.17 | 1.00 | 1.07 | 1.21 |
| 37 | a = 0.7 | 1.00 | 1.08 | 1.25 | 1.00 | 1.09 | 1.26 | 1.00 | 1.04 | 1.17 | 1.00 | 1.05 | 1.20 |
| 38 | a = 0.9 | 1.00 | 1.05 | 1.19 | 1.00 | 1.05 | 1.20 | 1.00 | 1.00 | 1.11 | 1.00 | 1.02 | 1.14 |
| 39 | b = 0.1 | 1.00 | 1.06 | 1.22 | 1.00 | 1.07 | 1.24 | 1.00 | 1.02 | 1.14 | 1.00 | 1.04 | 1.18 |
| 40 | b = 0.3 | 1.00 | 1.06 | 1.21 | 1.00 | 1.07 | 1.23 | 1.00 | 1.02 | 1.13 | 1.00 | 1.04 | 1.17 |
| 41 | u = 0.4 | 1.00 | 1.10 | 1.29 | 1.00 | 1.10 | 1.30 | 1.00 | 1.06 | 1.21 | 1.00 | 1.08 | 1.24 |
| 42 | u = 0.6 | 1.00 | 1.03 | 1.16 | 1.00 | 1.04 | 1.17 | 1.00 | 0.990 | 1.08 | 1.00 | 1.01 | 1.11 |
| 43 | v = 0.0 | 1.00 | 1.07 | 1.23 | 1.00 | 1.07 | 1.24 | 1.00 | 1.02 | 1.15 | 1.00 | 1.04 | 1.18 |
| 44 | v = 0.4 | 1.00 | 1.06 | 1.21 | 1.00 | 1.06 | 1.22 | 1.00 | 1.02 | 1.13 | 1.00 | 1.03 | 1.16 |
| 45 | U11/T1 = 0.6 | 1.00 | 0.984 | 1.13 | 1.00 | 0.990 | 1.14 | 1.00 | 0.955 | 1.06 | 1.00 | 0.965 | 1.09 |
| 46 | U11/T1 = 0.8 | 1.00 | 1.14 | 1.31 | 1.00 | 1.15 | 1.32 | 1.00 | 1.08 | 1.21 | 1.00 | 1.11 | 1.25 |
| 47 | U12/T2 = 0.4 | 1.00 | 1.16 | 1.22 | 1.00 | 1.17 | 1.23 | 1.00 | 1.10 | 1.14 | 1.00 | 1.13 | 1.17 |
| 48 | U12/T2 = 0.6 | 1.00 | 0.933 | 1.22 | 1.00 | 0.938 | 1.23 | 1.00 | 0.906 | 1.14 | 1.00 | 0.918 | 1.17 |
| 49 | U13/T3 = 0.2 | 1.00 | 1.06 | 1.45 | 1.00 | 1.07 | 1.47 | 1.00 | 1.02 | 1.33 | 1.00 | 1.04 | 1.38 |
| 50 | U13/T3 = 0.4 | 1.00 | 1.06 | 1.10 | 1.00 | 1.07 | 1.11 | 1.00 | 1.02 | 1.03 | 1.00 | 1.04 | 1.06 |
| 51 | s1 up 20% | 1.00 | 0.964 | 1.12 | 1.00 | 0.969 | 1.12 | 1.00 | 0.916 | 1.03 | 1.00 | 0.934 | 1.06 |
| 52 | s2 up 20% | 1.00 | 1.15 | 1.24 | 1.00 | 1.16 | 1.26 | 1.00 | 1.11 | 1.16 | 1.00 | 1.13 | 1.20 |
| 53 | s3 up 20% | 1.00 | 1.07 | 1.29 | 1.00 | 1.08 | 1.30 | 1.00 | 1.03 | 1.21 | 1.00 | 1.04 | 1.24 |
| 54 | m1 up 20% | 1.00 | 1.01 | 1.16 | 1.00 | 1.02 | 1.18 | 1.00 | 0.967 | 1.08 | 1.00 | 0.986 | 1.12 |
| 55 | m2 up 20% | 1.00 | 1.10 | 1.23 | 1.00 | 1.11 | 1.24 | 1.00 | 1.06 | 1.15 | 1.00 | 1.08 | 1.18 |
| 56 | m3 up 20% | 1.00 | 1.07 | 1.26 | 1.00 | 1.07 | 1.26 | 1.00 | 1.02 | 1.18 | 1.00 | 1.04 | 1.21 |
| 57 | r1 up 20% | 1.00 | 1.01 | 1.16 | 1.00 | 1.02 | 1.18 | 1.00 | 0.965 | 1.08 | 1.00 | 0.982 | 1.12 |
| 58 | r2 up 20% | 1.00 | 1.10 | 1.23 | 1.00 | 1.11 | 1.24 | 1.00 | 1.06 | 1.15 | 1.00 | 1.08 | 1.18 |
| 59 | r3 up 20% | 1.00 | 1.06 | 1.25 | 1.00 | 1.07 | 1.26 | 1.00 | 1.02 | 1.18 | 1.00 | 1.04 | 1.21 |

Table 3-A.10

## a. APPENDIX B - CORRECTIONS TO CALCULATIONS REFLECTING REVISED SUPPORT SOFTWARE DATA

At the 7 October 1976 meeting of the CFA Publications Subcommittee held at ECOM headquarters, Ft. Monmouth, New Jersey, Jim Wagner distributed a paper describing the revised results of the evaluation of the support software bases of the candidate architectures for the Military Computer Family [WagnJ76]. Its support software base results were different from those reported earlier in the main body of this report. The purpose of this appendix is to describe the main effects of these differences.

Figure 3-B.1 summarizes the revised software bases as reported in [WagnJ76]. Figure 3-B.2, also based on [WagnJ76], gives the estimated number of years to correct these deficiencies when 1, 2, and 3 million dollar/year are spent on support software development.

Software Base and Deficiency Comparison ($M=10^6$ dollars)

| Existing Base | | Deficiency | Total | Percent Availability |
|---|---|---|---|---|
| IBM | 32.269M | 9.595M | 41.864M | 77.08 |
| DEC | 22.220M | 19.130M | 41.350M | 53.74 |
| INT | 15.360M | 25.970M | 41.330M | 37.16 |

Figure 3-B.1

Years to Correct Deficiencies
Development Dollars

| | 1M | 2M | 3M |
|---|---|---|---|
| IBM | 10.5 | 5.5 | 4.5 |
| DEC | 20.0 | 11 | 8.5 |
| INT | 26.0 | 15 | 10 |

Figure 3-B.2

Using the values given in Figure 3-B.1, and in some cases applying the expressions described earlier, we obtained new input values for some of the parameters in the model:

| Parameter | Old Value | New Value |
|---|---|---|
| $U_{11}$ | 31.049M | 32.269M |
| $U_{12}$ | 20.079M | 22.220M |
| $U_{13}$ | 14.100M | 15.360M |
| $T_1$ | 44.604M | 41.864M |
| $T_2$ | 43.893M | 41.350M |
| $T_3$ | 44.040M | 41.330M |
| s' | 49.7 | 55.99 |
| k' | 0.05601 | 0.06337 |
| $f_m$ | 0.0795 | 0.08996 |
| $f_M$ | 2.7528 | 3.11464 |

In the earlier calculations, $Q_j$, the support software expenditure, was assumed to be a constant two million for the years J=2 through 13 (for most of the cases). The following calculations improve upon this assumption by making better use of the data provided in [WagnJ76]. In particular, we see from Figure 3-B.2 that if we spend two million per year it actually takes eleven years, or twenty-two million dollars, to correct a 19.30 million dollar deficiency in support software. This implies that in this case the dollar-effectiveness factor is (19.13/22) or 0.870 for the PDP-11. The comparable figures for the Interdata 8/32 and IBM 360/370 are 0.866 and 0.872, respectively. To account for these effects in the revised calculations we replaced $U_{jk}$ in Eq. (3.24) by $\gamma_k U_{jk}$ where $\gamma(1) = 0.872$, $\gamma(2) = 0.870$, and $\gamma(3) = 0.866$. Also we replaced $Q_j$ by $Q_{jk}$ in Eqs. (3.18) and (3.28) and for the $2 million dollar expenditure rate, let the $Q_{jk}$ matrix be zero except for the following elements:

$$Q_{j1} = 2x10^6 \text{ , } j=2, \ldots 7$$

$$Q_{j2} = 2x10^6 \text{ , } j=2, \ldots 12$$

$$Q_{j3} = 2x10^6 \text{ , } j=2, \ldots 16$$

The earlier calculations had assumed $Q_{jk}$ would be constant for all years, except the first, and thus didn't take into account the fact that once the support software deficiency had been corrected further expenditures would not be necessary.

Figures 3-B.1 and 3-B.2, and Tables 3-B.1 through 3-B.6 summarize the revised results for cases 3, 8, 13, 18, 23, and 28. Table 3-B.7 gives the results of assuming a software-to-hardware ratio of eight.

Comparing the revised results shown in Tables 3-B.1 through 3-B.7 with Figures 3-1 and 3-2, of the main text of this paper, we see the corrections have a relatively insignificant effect on the cost ratios reported earlier.

WagnJ76 Wagner, J., et. al., "Procedure for and Results of the Evaluation of the Software Bases of the Candidate Architectures for the Military Computer Family," 6 August 1976. Prepared by the Software Evaluation Methodology Subcommittee.

Year Case 3 (19 Oct 76)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 0.893 | 1.78 | 2.68 | 3.57 | 4.46 | 5.36 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 0.719 | 3.32 | 3.84 | 4.27 | 4.63 | 4.94 | 5.18 | 3.18 | 3.18 | 3.18 | 3.18 | 3.18 | 3.18 | 3 |
| (2) DEC | 1.07 | 3.96 | 4.72 | 5.34 | 5.85 | 6.27 | 6.60 | 6.25 | 5.93 | 5.64 | 5.37 | 5.13 | 3.13 | 4 |
| (3) INT | 1.43 | 4.63 | 5.64 | 6.45 | 7.12 | 7.67 | 8.09 | 7.62 | 7.18 | 6.78 | 6.42 | 6.09 | 5.79 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.98 | 1.69 | 33.6 | 55.0 | 81.1 | 112 | 147 | 180 | 213 | 246 | 280 | 313 | 346 | 9 |
| (2) DEC | 4.16 | 14.4 | 28.4 | 46.2 | 67.6 | 92.5 | 121 | 149 | 177 | 204 | 231 | 258 | 2837 | 10 |
| (3) INT | 4.01 | 13.8 | 27.2 | 44.1 | 64.2 | 87.4 | 114 | 139 | 165 | 190 | 214 | 239 | 262 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 0.835 | 0.852 | 0.845 | 0.840 | 0.834 | 0.826 | 0.823 | 0.838 | 0.831 | 0.829 | 0.825 | 0.824 | 0.818 | 13 |
| (3) INT | 0.805 | 0.816 | 0.810 | 0.802 | 0.792 | 0.780 | 0.776 | 0.772 | 0.775 | 0.772 | 0.764 | 0.764 | 0.757 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.75 | 15.1 | 28.2 | 43.6 | 60.6 | 78.7 | 97.5 | 114 | 128 | 142 | 154 | 165 | 175 | 15 |
| (2) DEC | 3.97 | 12.8 | 23.9 | 36.6 | 50.6 | 65.3 | 80.4 | 94.1 | 106 | 118 | 128 | 136 | 144 | 16 |
| (3) INT | 3.83 | 12.4 | 22.9 | 35.0 | 48.1 | 61.8 | 75.8 | 88.4 | 99.7 | 110 | 119 | 127 | 134 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 0.836 | 0.848 | 0.848 | 0.839 | 0.835 | 0.830 | 0.825 | 0.825 | 0.828 | 0.831 | 0.831 | 0.824 | 0.823 | 19 |
| (3) INT | 0.806 | 0.821 | 0.812 | 0.803 | 0.794 | 0.785 | 0.777 | 0.775 | 0.779 | 0.775 | 0.773 | 0.770 | 0.766 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1/8$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$ Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938$ $0.825$

Table 3-B.1

Year Case 8 (19 Oct 76)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 1.78 | 3.57 | 5.36 | 7.14 | 8.93 | 10.7 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 1.43 | 4.66 | 5.69 | 6.55 | 7.27 | 7.86 | 8.36 | 6.36 | 6.36 | 6.36 | 6.36 | 6.36 | 6.36 | 3 |
| (2) DEC | 2.14 | 5.94 | 7.45 | 8.69 | 9.71 | 10.5 | 11.2 | 10.5 | 9.86 | 9.28 | 8.75 | 8.26 | 6.26 | 4 |
| (3) INT | 2.86 | 7.27 | 9.27 | 10.9 | 12.3 | 13.3 | 14.2 | 13.2 | 12.3 | 11.6 | 10.8 | 10.2 | 9.57 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 5.69 | 18.9 | 37.5 | 61.2 | 89.9 | 124 | 162 | 198 | 235 | 271 | 307 | 344 | 380 | 9 |
| (2) DEC | 5.23 | 17.4 | 34.2 | 55.3 | 80.6 | 110 | 143 | 175 | 207 | 283 | 268 | 298 | 326 | 10 |
| (3) INT | 5.44 | 17.9 | 35.0 | 56.2 | 81.5 | 110 | 143 | 174 | 205 | 234 | 263 | 292 | 319 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 0.919 | 0.921 | 0.912 | 0.904 | 0.896 | 0.887 | 0.883 | 0.884 | 0.881 | 0.878 | 0.873 | 0.866 | 0.858 | 13 |
| (3) INT | 0.956 | 0.947 | 0.933 | 0.918 | 0.906 | 0.887 | 0.883 | 0.879 | 0.872 | 0.863 | 0.857 | 0.849 | 0.839 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 5.43 | 16.9 | 31.5 | 48.5 | 67.2 | 87.1 | 108 | 125 | 142 | 156 | 170 | 182 | 193 | 15 |
| (2) DEC | 4.99 | 15.5 | 28.7 | 43.9 | 60.4 | 77.6 | 95.2 | 111 | 125 | 138 | 149 | 159 | 167 | 16 |
| (3) INT | 5.19 | 16.0 | 29.4 | 44.7 | 61.2 | 78.2 | 95.5 | 111 | 124 | 136 | 147 | 157 | 165 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 0.919 | 0.917 | 0.911 | 0.905 | 0.899 | 0.891 | 0.881 | 0.888 | 0.880 | 0.885 | 0.876 | 0.874 | 0.865 | 19 |
| (3) INT | 0.956 | 0.947 | 0.933 | 0.922 | 0.911 | 0.898 | 0.884 | 0.868 | 0.873 | 0.872 | 0.865 | 0.863 | 0.855 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1/4$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$ Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938$ $0.825$

Table 3-B.2

Year Case 13 (19 Oct 76)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 3.57 | 7.14 | 10.7 | 14.3 | 17.9 | 21.4 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 2.88 | 7.31 | 9.36 | 11.1 | 12.6 | 13.7 | 14.7 | 12.7 | 12.7 | 12.7 | 12.7 | 12.7 | 12.7 | 3 |
| (2) DEC | 4.28 | 9.88 | 12.9 | 15.4 | 17.5 | 19.0 | 20.4 | 19.0 | 17.7 | 16.6 | 15.5 | 14.5 | 12.5 | 4 |
| (3) INT | 5.74 | 12.5 | 16.5 | 19.8 | 22.6 | 24.6 | 26.4 | 24.5 | 22.7 | 21.1 | 19.7 | 18.4 | 17.1 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 7.14 | 23.0 | 45.2 | 73.5 | 108 | 147 | 192 | 234 | 277 | 320 | 363 | 405 | 448 | 9 |
| (2) DEC | 7.37 | 23.5 | 45.7 | 73.5 | 106 | 144 | 186 | 227 | 267 | 305 | 342 | 378 | 413 | 10 |
| (3) INT | 8.32 | 26.0 | 50.4 | 80.6 | 116 | 156 | 201 | 244 | 284 | 324 | 362 | 398 | 433 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.03 | 1.02 | 1.01 | 1.00 | 0.981 | 0.980 | 0.969 | 0.970 | 0.964 | 0.953 | 0.942 | 0.933 | 0.922 | 13 |
| (3) INT | 1.16 | 1.13 | 1.12 | 1.10 | 1.07 | 1.06 | 1.05 | 1.04 | 1.02 | 1.01 | 0.997 | 0.983 | 0.966 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 6.81 | 2.06 | 38.1 | 58.4 | 80.6 | 104 | 128 | 149 | 168 | 185 | 201 | 215 | 228 | 15 |
| (2) DEC | 7.04 | 21.0 | 38.5 | 58.4 | 80.0 | 102 | 125 | 145 | 162 | 178 | 192 | 204 | 214 | 16 |
| (3) INT | 7.93 | 23.3 | 42.4 | 64.1 | 87.3 | 111 | 135 | 156 | 174 | 190 | 204 | 216 | 227 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.03 | 1.02 | 1.01 | 1.00 | 0.992 | 0.981 | 0.976 | 0.973 | 0.964 | 0.962 | 0.955 | 0.949 | 0.938 | 19 |
| (3) INT | 1.16 | 1.13 | 1.11 | 1.10 | 1.08 | 1.07 | 1.05 | 1.05 | 1.04 | 1.03 | 1.01 | 1.00 | 0.996 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1/2$  Dev. Cycle = 7  $\alpha = 0.65$  g = 1.5  a = 0.8  b = 0.2  Revised Support Software Base

$s_1, s_2, s_3$ = 1.208, 1.000, 0.828  $m_1, m_2, m_3$ = 1.266, 0.928, 0.850  $r_1, r_2, r_3$ = 1.292, 0.938 0.825

Table 3-B.3

Year Case 18 (Reference, 19 Oct 76)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 5.75 | 12.6 | 16.7 | 20.2 | 23.1 | 25.5 | 25.4 | 25.4 | 25.4 | 25.4 | 25.4 | 25.4 | 25.4 | 3 |
| (2) DEC | 8.57 | 17.8 | 23.8 | 28.8 | 32.8 | 36.1 | 38.8 | 36.0 | 33.4 | 31.1 | 29.0 | 27.0 | 25.0 | 4 |
| (3) INT | 11.5 | 23.1 | 31.1 | 37.7 | 43.0 | 47.3 | 50.7 | 46.9 | 43.4 | 40.3 | 37.4 | 34.7 | 32.3 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 10.0 | 31.2 | 60.8 | 98.2 | 143 | 194 | 251 | 307 | 362 | 418 | 473 | 528 | 584 | 9 |
| (2) DEC | 11.6 | 35.7 | 68.8 | 110 | 158 | 213 | 274 | 331 | 387 | 440 | 490 | 539 | 586 | 10 |
| (3) INT | 14.0 | 42.3 | 81.2 | 129 | 185 | 248 | 317 | 382 | 444 | 502 | 558 | 610 | 661 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.16 | 1.14 | 1.13 | 1.12 | 1.10 | 1.10 | 1.09 | 1.08 | 1.07 | 1.05 | 1.04 | 1.02 | 1.00 | 13 |
| (3) INT | 1.40 | 1.36 | 1.34 | 1.31 | 1.29 | 1.28 | 1.26 | 1.24 | 1.23 | 1.20 | 1.18 | 1.16 | 1.13 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 9.55 | 28.0 | 51.3 | 78.1 | 107 | 137 | 168 | 195 | 220 | 242 | 263 | 281 | 298 | 15 |
| (2) DEC | 11.1 | 31.9 | 58.0 | 87.6 | 119 | 152 | 184 | 212 | 237 | 258 | 277 | 293 | 307 | 16 |
| (3) INT | 13.4 | 37.9 | 68.6 | 103 | 140 | 177 | 213 | 245 | 273 | 296 | 317 | 334 | 350 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.16 | 1.14 | 1.13 | 1.12 | 1.11 | 1.11 | 1.09 | 1.09 | 1.08 | 1.07 | 1.05 | 1.04 | 1.03 | 19 |
| (3) INT | 1.40 | 1.35 | 1.34 | 1.32 | 1.31 | 1.29 | 1.27 | 1.26 | 1.24 | 1.22 | 1.20 | 1.19 | 1.17 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 1$ Dev. Cycle = 7 $\alpha = 0.65$ g = 1.5 a = 0.8 b = 0.2 Revised Support Software Base

$s_1, s_2, s_3$ = 1.208, 1.000, 0.828 $m_1, m_2, m_3$ = 1.266, 0.928, 0.850 $r_1, r_2, r_3$ = 1.292, 0.938 0.825

Table 3-B.4

Year Case 23 (19 Oct 76)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 14.3 | 28.6 | 42.9 | 57.1 | 71.4 | 85.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 11.5 | 23.3 | 31.5 | 38.4 | 44.2 | 48.9 | 52.8 | 50.8 | 50.8 | 50.8 | 50.8 | 50.8 | 50.8 | 3 |
| (2) DEC | 17.2 | 33.6 | 45.6 | 55.5 | 63.6 | 70.3 | 75.6 | 70.0 | 64.9 | 60.3 | 56.0 | 52.1 | 50.1 | 4 |
| (3) INT | 23.0 | 44.2 | 60.2 | 73.3 | 84.0 | 92.6 | 99.4 | 91.8 | 84.9 | 78.5 | 72.7 | 67.4 | 62.6 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 15.8 | 47.6 | 92.0 | 148 | 213 | 288 | 371 | 452 | 532 | 613 | 694 | 775 | 856 | 9 |
| (2) DEC | 20.2 | 60.0 | 115 | 183 | 262 | 351 | 448 | 540 | 627 | 709 | 787 | 860 | 932 | 10 |
| (3) INT | 25.6 | 75.0 | 143 | 227 | 324 | 432 | 549 | 659 | 762 | 859 | 950 | 1036 | 1116 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.28 | 1.26 | 1.25 | 1.24 | 1.23 | 1.22 | 1.21 | 1.19 | 1.18 | 1.16 | 1.13 | 1.11 | 1.09 | 13 |
| (3) INT | 1.62 | 1.58 | 1.55 | 1.53 | 1.52 | 1.50 | 1.48 | 1.46 | 1.43 | 1.40 | 1.37 | 1.34 | 1.30 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 15.0 | 42.7 | 77.6 | 118 | 160 | 204 | 249 | 288 | 324 | 357 | 387 | 414 | 438 | 15 |
| (2) DEC | 19.3 | 53.8 | 97.1 | 146 | 197 | 250 | 302 | 347 | 385 | 419 | 447 | 472 | 494 | 16 |
| (3) INT | 24.4 | 67.2 | 121 | 181 | 244 | 308 | 371 | 425 | 470 | 510 | 543 | 572 | 596 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.29 | 1.26 | 1.25 | 1.24 | 1.23 | 1.22 | 1.21 | 1.20 | 1.19 | 1.17 | 1.16 | 1.40 | 1.13 | 19 |
| (3) INT | 1.63 | 1.57 | 1.56 | 1.53 | 1.52 | 1.51 | 1.49 | 1.48 | 1.45 | 1.43 | 1.40 | 1.38 | 1.36 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 2$  Dev. Cycle = 7  $\alpha = 0.65$  $g = 1.5$  $a = 0.8$  $b = 0.2$  Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$  $m_1, m_2, m_3 = 1.266, 0.928, 0.850$  $r_1, r_2, r_3 = 1.292, 0.938$  $0.825$

Table 3-B.5

Year Case 28 (19 Oct 76)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 28.6 | 57.1 | 85.7 | 114 | 143 | 171 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 23.0 | 44.5 | 61.0 | 74.6 | 86.4 | 95.6 | 104 | 102 | 102 | 102 | 102 | 102 | 102 | 3 |
| (2) DEC | 34.3 | 65.0 | 89.1 | 109 | 126 | 138 | 149 | 138 | 128 | 118 | 110 | 102 | 100 | 4 |
| (3) INT | 46.0 | 86.3 | 118 | 144 | 166 | 183 | 197 | 182 | 168 | 155 | 144 | 133 | 123 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 27.3 | 80.4 | 154 | 246 | 354 | 475 | 609 | 741 | 872 | 1004 | 1136 | 1267 | 1399 | 9 |
| (2) DEC | 37.4 | 109 | 207 | 328 | 469 | 626 | 797 | 957 | 1106 | 1247 | 1379 | 1503 | 1625 | 10 |
| (3) INT | 48.5 | 140 | 266 | 421 | 600 | 798 | 1013 | 1213 | 1399 | 1573 | 1734 | 1885 | 2026 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.37 | 1.36 | 1.34 | 1.33 | 1.32 | 1.32 | 1.31 | 1.29 | 1.27 | 1.24 | 1.21 | 1.19 | 1.16 | 13 |
| (3) INT | 1.78 | 1.74 | 1.73 | 1.71 | 1.69 | 1.68 | 1.66 | 1.64 | 1.60 | 1.57 | 1.53 | 1.49 | 1.45 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 26.0 | 72.1 | 130 | 196 | 266 | 338 | 410 | 474 | 532 | 586 | 634 | 678 | 718 | 15 |
| (2) DEC | 35.7 | 97.5 | 175 | 262 | 354 | 447 | 538 | 616 | 683 | 739 | 788 | 829 | 866 | 16 |
| (3) INT | 46.3 | 126 | 225 | 336 | 453 | 570 | 685 | 783 | 865 | 936 | 995 | 1045 | 1088 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.37 | 1.35 | 1.35 | 1.34 | 1.33 | 1.32 | 1.31 | 1.30 | 1.28 | 1.26 | 1.24 | 1.22 | 1.21 | 19 |
| (3) INT | 1.78 | 1.75 | 1.73 | 1.71 | 1.70 | 1.69 | 1.67 | 1.65 | 1.62 | 1.60 | 1.57 | 1.54 | 1.52 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 4$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$ Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938$ 0.825

Table 3-B.6

Year Extra Case (19 Oct 76)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | Row |
| Base Appl. Sftwe Exp. | 57.1 | 114 | 171 | 228 | 286 | 343 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
| Base Hdwe Exp. ($Mil) | 7.14 | 14.3 | 21.4 | 28.6 | 35.7 | 42.8 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 2 |
| Total Yearly Software | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 46.0 | 86.8 | 120 | 147 | 171 | 190 | 205 | 203 | 203 | 203 | 203 | 203 | 203 | 3 |
| (2) DEC | 68.5 | 128 | 176 | 216 | 249 | 275 | 296 | 274 | 254 | 235 | 218 | 202 | 201 | 4 |
| (3) INT | 91.7 | 170 | 234 | 287 | 330 | 365 | 392 | 361 | 334 | 308 | 285 | 264 | 244 | 5 |
| Total Yearly Hardware | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 4.26 | 8.59 | 12.9 | 17.2 | 21.4 | 25.7 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 6 |
| (2) DEC | 3.09 | 6.22 | 9.32 | 12.4 | 15.5 | 18.6 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 21.8 | 7 |
| (3) INT | 2.58 | 5.20 | 7.77 | 10.4 | 13.0 | 15.6 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 | 8 |
| Total Non-Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 50.2 | 146 | 278 | 443 | 635 | 850 | 1086 | 1319 | 1553 | 1786 | 2019 | 2253 | 2486 | 9 |
| (2) DEC | 71.6 | 206 | 391 | 619 | 883 | 1177 | 1495 | 1791 | 2066 | 2323 | 2563 | 2787 | 3010 | 10 |
| (3) INT | 94.3 | 270 | 512 | 809 | 1152 | 1532 | 1942 | 2322 | 2674 | 3000 | 3303 | 3585 | 3847 | 11 |
| Total Non-Discounted Cum. Cost Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 12 |
| (2) DEC | 1.43 | 1.41 | 1.41 | 1.40 | 1.30 | 1.38 | 1.38 | 1.36 | 1.33 | 1.30 | 1.27 | 1.24 | 1.21 | 13 |
| (3) INT | 1.88 | 1.85 | 1.84 | 1.83 | 1.81 | 1.80 | 1.79 | 1.76 | 1.72 | 1.68 | 1.64 | 1.59 | 1.55 | 14 |
| Total Discounted Cumulative Cost | | | | | | | | | | | | | | |
| (1) IBM ($Mil) | 47.9 | 131 | 235 | 353 | 478 | 606 | 731 | 846 | 949 | 1044 | 1130 | 1208 | 1279 | 15 |
| (2) DEC | 68.3 | 185 | 330 | 494 | 666 | 840 | 1010 | 1155 | 1277 | 1381 | 1469 | 1544 | 1612 | 16 |
| (3) INT | 90.0 | 242 | 433 | 646 | 870 | 1095 | 1313 | 1499 | 1655 | 1788 | 1899 | 1993 | 2073 | 17 |
| Total Discounted Cum. Ratios | | | | | | | | | | | | | | |
| (1) IBM | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 18 |
| (2) DEC | 1.42 | 1.41 | 1.40 | 1.40 | 1.39 | 1.39 | 1.38 | 1.36 | 1.34 | 1.32 | 1.30 | 1.28 | 1.26 | 19 |
| (3) INT | 1.88 | 1.85 | 1.84 | 1.83 | 1.82 | 1.81 | 1.80 | 1.77 | 1.74 | 1.71 | 1.68 | 1.65 | 1.62 | 20 |
| Discount Factor (10%) | 0.954 | 0.867 | 0.788 | 0.717 | 0.652 | 0.592 | 0.538 | 0.489 | 0.445 | 0.405 | 0.368 | 0.334 | 0.304 | 21 |

$\rho = 8$  Dev. Cycle = 7  $\alpha = 0.65$  $g = 1.5$  $a = 0.8$  $b = 0.2$  Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$  $m_1, m_2, m_3 = 1.266, 0.928, 0.850$  $r_1, r_2, r_3 = 1.292, 0.938\ \ 0.825$

Table 3-B.7

## 4. CONCLUSIONS

The two models serve as checks against one another. The bottom-up results indicate that in most circumstances the DEC PDP-11 is superior to both the IBM S/370 and Interdata 8/32 architectures. The top-down model results, on the other hand, indicate that the S/370 is superior for high (greater than one) software-to-hardware cost ratios, while the Interdata 8/32 is slightly better for low (less than one-fourth) ratios, and the PDP-11 is best in between. These apparently conflicting results were found to be due to uncertainties in the input data, to different input requirements, to contrasting basic model assumptions, and to different methods of combining the same input data.

For example, the bottom-up model weights the raw S, M, and R data, provided by CMU for the individual test programs, according to the estimated relevance of each program in each system application. It then combines these into the composite processor speed and static storage ratios, $a_{ij}$, and $b_{ij}$. The top-down model, on the other hand, uses composite S, M, R ratios, which were derived by CMU from the individual S, M, R measures for each test program and which were weighted by CMU to obtain minimum statistical variance in these ratios rather than to reflect the importance of particular application programs. A result of these two different approaches to using the individual test program S, M, and R data is a difference in the computed architectural efficiency of the Interdata 8/32 as compared to the PDP-11. In the first case they are comparable, in the second the 8/32 is superior. A further result of this difference is that if the unweighted S, M, and R data are used in the bottom-up model, then the 8/32 becomes the superior architecture in the 1976 calculations when the hardware-software cost ratio is high. This agrees with the top-down model results. Conversely, if the S, M, and R data used in the top-down model were weighted as in the bottom-up model, better agreement between the models would result.

As another example, the assumptions leading to the ratio of software costs to hardware costs are clearly among the most important to the ultimate results, while at the same time are among the most difficult to support with actual data.

The uncertainty calculations in Section 3.4 for the top-down model could be applied to the bottom-up model with similar results expected. Because of the size of these uncertainties, the results of the models must be interpreted with caution. By chance, each of the three architectures evaluated had either superior hardware attributes (the 8/32), or superior software attributes (the S/370), or a good combination of the two (the PDP-11). As a result, the combined hardware-software effectiveness of the three architectures were relatively close. Probably the strongest conclusions to be derived from the life cycle cost evaluations are that, within the uncertainties resulting from propagating errors in the input data throughout each models calculations, (1) the models agree and (2) all three architectures would be comparable choices based on life-cycle costs.